Introduction

The following document represents NASA Mir science program results to date. Each investigation is summarized, and includes the objectives, operations, results, and conclusions. A publications list is available for some investigations.

For 1 year following the conclusion of NASA 7, investigators have exclusive use of these data in order to compile and publish their results, therefore many results are not yet available.

As results become available after the proprietary period, they will be available on a Shuttle Mir History Web site, beginning July 1999.

Contents

ADVANCED TECHNOLOGY

EARTH SCIENCES

FUNDAMENTAL BIOLOGY

HUMAN LIFE SCIENCES

INTERNATIONAL SPACE STATION

LIFE SUPPORT RISK MITIGATION

MICROGRAVITY

Investigation Title: Astroculture (ASC)

Principal Investigator(s): Raymond Bula, Ph.D., University of Wisconsin-Madison

Additional Investigators: Weijia Zhou

INVESTIGATION OBJECTIVES

The objective of the ASTROCULTURE™ experiment was to determine if wheat plants, a commercially important crop species, would complete their life cycle in microgravity if grown in a plant chamber that provided a high level of control of the critically important environmental variables.

PHASE 1 MISSIONS

NASA 7

OPERATIONAL ACTIVITIES

Wheat seeds were planted prior to launch. Following the transfer of the astroculture hardware from the Shuttle, STS-89, to the Mir, the experiment was activated. On activation of the ASTROCULTURE™ (ASC-7) flight unit, nutrient solution was transferred from the storage reservoir to the root material for initiating germination of the wheat seeds. During the subsequent growing period of 70 to 80 days, the environmental data recorded by the ASC-7 computer were downlinked to ground controllers. Periodically, video records were to have been made using the on-board camcorder attached to the video camera in the ASC-7 flight unit. After 70 to 80 days, the crew initiated a preprogrammed sequence of environmental changes in the plant chamber that would result in drying the plant material and thereby preserving it until it was returned on STS-91.

RESULTS

The flight unit was activated after STS-89 undocked from the Mir and functioned nominally for approximately 23.5 hours. At that time, a malfunction error was displayed. It was determined that the CPU board of the computer in the flight unit was not functioning.

A replacement board was delivered to Mir and installed without any problem. The flight unit was restarted and functioned nominally for approximately 2 hours and then shut down. After approximately another 2 hours the flight unit restarted. It was decided that this malfunction most likely was due to the internal temperature in the flight unit (not in the plant chamber) was reaching a level that activated the thermal cut-off switch and opened the power circuit to the flight unit. After several such cycles, it was decided to deactivate the flight unit and terminate the experiment.

CONCLUSIONS

No conclusions

PUBLICATIONS

No publications

Investigation Title: Commercial Generic Bioprocessing Apparatus (CGBA)

Principal Investigator(s): Louis Stodieck, Ph.D., University of Colorado at Boulder

Additional Investigators: Sportiello, Tran, Korzun, Cape, Todd, Kundrot, Redman, Doyle, Shoham, Marchin, Urban, Hilaire, Guikema, Li, MacCallum, Manfredi, Juergensmeyer, Juergensmeyer, Kacena, Osslund, Villa, Heyanga, Mahady, Wachtel, Stoner, Clawson

INVESTIGATION OBJECTIVES

Improve processes used in terrestrial biotechnology or create new biologically-derived products based on the novel scientific insight gained from observing how microgravity affects various functions of living systems. CGBA investigation categories: protein crystallization, seedling and plant tissue cultures, biomaterials, cell separation, bacterial growth and antibiotic resistance, water purification and biopharmaceutical production.

PHASE 1 MISSIONS

NASA 3, NASA 6

OPERATIONAL ACTIVITIES

The CGBA payload operations were largely automated. Crew operational activities included transfer to and from Mir and regular periodic status checks.

RESULTS

High quality lysozyme crystals exhibiting approximately half the mosaicity (level of disorder) of the ground crystals grown on NASA 3 using 5 techniques and a single very large (~8mm x 8mm) Granulocyte-Colony Stimulating Factor (G-CSF or NeupogenÆ) grown on NASA 6; Oligonucleotide crystals grown in space diffracted to 0.9 Angstrom units compared to the slightly less ordered ground crystal diffraction of 0.95 Angstrom units; Fungal-fighting abilities of plant seedlings maintained in microgravity; iodine resistance of Pseudomonas observed in space; aquatic plants, invertebrates and microbes were maintained in a closed system with various morphological and metabolic differences noted in space; No clear pattern of postflight antibiotic resistance noted, but variations between bacteria and antibiotic combinations suggests efflux pump role.

CONCLUSIONS

A wide variety of industry-sponsored research projects were supported by the CGBA payload. All are part of an ongoing program that provides commercial scientists with access to space. Each flight experiment represents a specific step in a process intended to open biotechnology opportunities that derive benefit from the unique environment of space. The Mir Phase 1 Program provided many “lessons learned” which have provided researchers a bridging opportunity to evolve investigations from short-duration Shuttle missions into continuous research carried out on board the ISS.

PUBLICATIONS

Articles appearing in -- Spacebound 97 Proceedings, Microgravity Science and Technology and Current Microbiology

Investigation Title: Commercial Protein Crystal Growth (CPCG)

Principal Investigator(s): Lawrence Delucas, Ph.D., University of Alabama at Birmingham

Additional Investigators: Shigeo Aibara, Louis Delbaire, James Knox, Karen Moore, Stephen Quirk, Michail Spangfort, Narayana Sthanam.

INVESTIGATION OBJECTIVES

By conducting technology experiments in space, new insight may be gained concerning industrial needs and technological developments on Earth. This experiment investigated the process of growing protein crystals and biological macromolecules under microgravity conditions to facilitate the analysis of their structure.

PHASE 1 MISSIONS

STS-79, STS-86

OPERATIONAL ACTIVITIES

STS-79 - The Commercial Protein Crystal Growth Experiments flew aboard STS-79 flew as a sortie mission in the Shuttle middeck. The vapor diffusion protein crystal growth experiments aboard STS-79 involved nine proteins in the third flight of the Commercial Protein Crystal Growth hardware. This hardware consisted of 128 protein crystal growth chambers contained in the Commercial Refrigerator/Incubator Module (CRIM). The experiments were conducted at 22 degrees C. The proteins involved in these experiments were Trypsin Inhibitor, PEP Carboxykinase Complex, Van X, Van A, B, GDP Mannose Mannosyl Hydrolase, Grass Pollen Allergen Ph1 P5, Factor D, and Lysozyme.

STS-86 - The Commercial Protein Crystal Growth Experiment flew aboard STS-86 as sortie mission in the Shuttle middeck.

RESULTS

STS-79 - In general, the preliminary results indicate that protein crystal growth experiments on STS-79 were quite successful. Analysis of the x-ray diffraction data from these crystals is ongoing.

STS-86 - There was a tremendous difference between the space- and Earth-grown crystals with the microgravity crystals exhibiting vastly superior conformation and optical clarity. They were also very large; being rhombohedra of 1.5 mm on a side in some cases. X-ray diffraction studies are underway.

CONCLUSIONS

STS-79 - In general, the preliminary results indicated that the experiments produced diffraction-sized crystals of five of the nine proteins flown, with crystals of another protein marginal for x-ray diffraction studies. One of the proteins, GDP Mannosyl Mannose Hydrolase, produced crystals with the best macroscopic clarity yet seen for this protein. Additionally, valuable information was obtained about the optimum crystal growth conditions for microgravity experiments.

PUBLICATIONS

None.

Investigation Title: Materials in Devices as Superconductors (MiDAS)

Principal Investigator(s): Stephanie Wise, NASA/Langley Research Center

Additional Investigators:

INVESTIGATION OBJECTIVES

1. To determine the effects of microgravity and space flight on the electrical and magnetic properties of high-temperature superconductivity materials (HTS).

PHASE 1 MISSIONS

NASA 3

OPERATIONAL ACTIVITIES

MiDAS was launched on STS-79 and transferred to the Mir Space Station. It stayed on the Mir for the NASA 3 mission and brought back to the ground on STS-81.

RESULTS

The MIDAS research results show that superconductive thick films can be successfully produced, integrated into durable electronic packages, and operated in a microgravity environment. While aboard the Mir, the specimens exhibited electrical properties that approximate those observed on the ground. Furthermore, the data show that the critical transition temperature (Tc) and critical current density (Jc) properties did not degrade over time while in space, as evidenced by both the on-orbit and postflight data. Finally, the electrical resistance and current versus voltage characteristics of the thick film specimens when taken at temperatures above the Tc showed no change during the 90 days of measurements on orbit. These findings demonstrate the survivability of the superconductive films and serve to relieve some of the concerns associated with the incorporation of these new materials into space systems.

CONCLUSIONS

See Results

PUBLICATIONS

No publications

Investigation Title: Optizone Liquid Phase Sintering Experiment (OLiPSE) (LPS)

Principal Investigator(s): James Smith, Ph.D., University of Alabama at Huntsville

Additional Investigators:

INVESTIGATION OBJECTIVES

1. To study the affect of microgravity on the formation of defects (voids) in sintered products, wetting and alloy formation, and grain sizes and shapes.
2. Analyze the effects of wetting and alloy formation.
3. Study grain sizes and shapes.

PHASE 1

NASA 2, NASA 6, NASA 7

OPERATIONAL ACTIVITIES

NASA 2 - (OLiPSE) consisted of 16 sample ampoules, two calibration sample ampoules, and on-orbit support equipment. The samples were processed in the Optizon high temperature furnace available in the Kristall module of the Mir Space Station. The samples were carried aloft on STS-76 and processed between March 30 to April 20,1996. Of the the 16 sample ampoules, 13 ampoules were processed. NASA 6 - During the calibration of Optizon furnace it was learned that it was malfunctioning, so the project was moved to NASA 7.

RESULTS

NASA 2 - Analysis of the successfully processed samples resulted in data collection for densification, microstructural analysis, pore behavior, grain growth, coordination number, solid volume fraction and dihedral angle. Densification was determined with the water displacement technique. All four samples show positive densification and the densification decreased as the liquid volume increased. Stress intensive regions resulted in a increase liquid volume fraction 10 -20 %. This stress is the driving mechanism to pore filling. However, no pore filling was observed. Pores were uniformly distributed in the microstructure in the 80Fe-20Cu sample. The heavily interconnected grains preclude pore migration and growth. There was little pore coarsening in the 80Fe-20Cu sample. It was observed that grain size decreased as the percent of liquid volume increased. The measured maximum grain size was 1.5 times the mean grain size as predicted from the LSW model under steady state conditions. Wetting of Fe particles by liquid copper results in a reduction of interparticle contact. This reduction corresponds to a decrease in the three-dimensional coordination number with increasing liquid volume fraction. The coordination numbers obtained from the 60Fe-40Cu and 50Fe-50Cu samples are lower than those obtained from the same composition of ECLiPSE samples. The mean dihedral angles show little change along the liquid volume fraction. This indicated an equilibrium dehedral angle around 55 degrees may have been achieved.

NASA 6 - One ampoule was returned on STS-89. Problems with Optizon furnace caused this experiment to be moved from NASA 6 to NASA 7.

NASA 7 - Results from NASA 7 are not available at this time

CONCLUSIONS

NASA 2 - Though the data set was not complete due to the anomaly previously discussed, shown that the samples processed produced significant scientific results and raised additional questions that the samples processed during NASA 7/Mir 25 should resolve.

PUBLICATIONS

1. "Optizone Liquid Phase Sintering Experiments (OLiPSE-01) Aboard the Mir Station: Performance and Preliminary Results", with He, Y., Ye, S., Kuruvilla, A., Savin, S., Ivanov, A., Markov, E, Andropov, V.,

Bratukin, U. Putin, G. and Smith, J., Proceedings of the Joint Xth European and VIth Russian Symposium on Physical Sciences in Microgravity, pp 133-135, St. Petersburg Russia, June, 1997.

2. “Preliminary Results From Liquid Phase Sintering Aboard the Russian Mir Station”, with He, Y, Ye, S., Kuruvilla, A., and Smith, J. To appear, Proceedings of SpaceBound 97, Montreal Canada, May 11-15, 1997.

3. “High Temperature Liquid Phase Sintering: OLIPSE-01,” with He, Y., Ye, S.and Smith, J., Proceedings of the Phase 1 Research Program Interim Results Symposium, Microgravity and Materials Sciences Section, pp 61-74, August 5-7,1997.

4. He, S. Ye, A. K. Kuruvilla, and J.E. Smith Jr., “*Preliminary Results from Liquid Phase Sintering Studies Aboard Russian Mir Station*”, 9th International Symposium on Experimental Methods for Microgravity Materials Science, TMS publication (in CD-ROM format), compiled and edited by Dr. Robert A. Schiffman. 1997.

Investigation Title: Calibration & Validation of Priroda Microwave Sensors (IKAR)

Principal Investigator(s): James C. Shiue, NASA/Goddard Space Flight Center

Additional Investigator(s): Neon A. Armand; Eni G. Njoku; William Wilson

INVESTIGATION OBJECTIVES

The objective of this experiment was to document sensor characteristics and validate sensor retrieval algorithms.

PHASE 1 MISSIONS

This experiment was canceled after a soyuz craft collided with the Mir Space Station. Sufficient power was not available to activate the Priroda sensors.

RESULTS

None expected from PI

CONCLUSIONS

None expected from PI

PUBLICATIONS

None expected from PI

Investigation Title: Comparison of Atmospheric Chemistry Sensors on Priroda & American Satellites (Chemistry)

Principal Investigator(s): Jack A. Kaye, NASA/Headquarters

Additional Investigator(s): Not provided by PI

INVESTIGATION OBJECTIVES

The objective of the experiment was to make a comparison of contemporaneous data from multiple sensors.

PHASE 1 MISSIONS

This experiment was canceled after a soyuz craft collided with the Mir Space Station. Sufficient power was not available to activate the Priroda sensors.

RESULTS

None expected from PI

CONCLUSIONS

None expected from PI

PUBLICATIONS

None expected from PI

Investigation Title: Mir Window Survey

Principal Investigators: Kamlesh P. Lulla, Ph.D. and Premkumar B. Saganti, Ph.D., NASA/Johnson Space Center; Stainslav Savachinko, Ph.D. and Ivan Firsov, Ph.D., RSC/Energia

Additional Investigators: Gregory J. Byrne, Ph.D., Jon Disler, and Cindy Evans, Ph.D.

INVESTIGATION OBJECTIVES

1. To collect photographic and video data of the optical windows on the Mir Complex.
2. To analyze the collected data for estimating the optical degradation and for documenting the existing condition of the window surfaces.

Mir Window Survey was a first of its kind to photo document the condition of optical windows. Mir Complex has a total of 30 different windows in various modules. Some windows have been exposed to the space environment for about 12 years and some windows have been exposed to the space environment for about three years.

PHASE 1 MISSIONS

NASA 5 - NASA 7

OPERATIONAL ACTIVITIES

Acquisition of photographic data with a 35 mm Nikon-F3 film camera using various zoom lenses. Acquisition of video survey data of the window panes and window housing.

RESULTS

Data for a total of eight different windows were collected during three different missions (NASA 5, 6, and 7) as a specific NASA-Mir Mission Science objective. Final analysis of the window data was completed and presented at the Phase 1 Mission Science Symposium in November 1998. Most exterior window panes showed contamination deposits, Micrometeoroid and Orbital Debris (MMOD) impacts, and other degradations (scuff marks and scratches). Qualitative descriptions of most features and quantitative measurements of most impacts were presented as part of the results.

CONCLUSIONS

Most interior window panes and interior window housing were found to be in remarkably good condition. Most exterior window panes showed significant damage due to MMOD impacts, external contamination deposits, and other degradations (scuff marks) some could have been EVA related.

PUBLICATIONS

Mission Science Reports - 1997, 1998, and 1999

Mission Science Symposia - 1997, 1998

JSC Technical Report - 1999

Invited Paper - GeoCarto International Special Edition - 1999

Investigation Title: Regional & Temporal Variability of Primary Productivity in Ocean Shelf Waters (Color)

Principal Investigator(s): Frank E. Muller-Karger, University of South Florida

Additional Investigator(s): O. Kopelevich

INVESTIGATION OBJECTIVES

The objectives of this experiment were: to quantify the role of continental margins in global BGC, to investigate physical & chemical factors controlling production, to investigate trajectory of materials supplied by upwelling & river discharge, to compare MOZ-Obzur & SeaWiFS data, to investigate use of MOZ-Obzur to correct SeaWiFS data for aerosol distribution, and to assure data comparability between Priroda and SeaWiFS.

PHASE 1 MISSIONS

This experiment was canceled after a soyuz craft collided with the Mir Space Station. Sufficient power was not available to activate the Priroda sensors.

RESULTS

None expected from PI

CONCLUSIONS

None expected from PI

PUBLICATIONS

None expected from PI

Investigation Title: Test Site Monitoring (TEST)

Principal Investigator(s): Cynthia Evans, Lockheed Martin

Additional Investigator(s): Kamlesh Lulla; Lev Desinov

INVESTIGATION OBJECTIVES

The objective of this experiment was to monitor changes in land cover and condition, lake levels, etc., at selected test sites in support of the US Earth Observations System Program and global change research.

PHASE 1 MISSIONS

NASA 2 - NASA 7

OPERATIONAL ACTIVITIES

This experiment was merged with the Visual Earth Observations (Obs) experiment.

Investigation Title: Validation of Biosphere-Atmosphere Interchange Model for Northern Prairies (Prairies)

Principal Investigator(s): Anthony W. England, University of Michigan

Additional Investigator(s): A. M. Shutko

INVESTIGATION OBJECTIVES

The objective of the experiment was to validate biosphere-atmosphere interchange model of northern prairies.

PHASE 1 MISSIONS

This experiment was canceled after a soyuz craft collided with the Mir Space Station. Sufficient power was not available to activate the Priroda sensors.

RESULTS

None expected from PI

CONCLUSIONS

None expected from PI

PUBLICATIONS

None expected from PI

Investigation Title: Validation of Priroda Rain Observations (Rain)

Principal Investigator(s): Otto W. Thiele, NASA/Marshall Space Flight Center

Additional Investigator(s): Not provided by PI

INVESTIGATION OBJECTIVES

The objective of the experiment was to validate rain rate estimations from Priroda sensors.

PHASE 1 MISSIONS

This experiment was canceled after a soyuz craft collided with the Mir Space Station. Sufficient power was not available to activate the Priroda sensors.

RESULTS

None expected from PI

CONCLUSIONS

None expected from PI

PUBLICATIONS

None expected from PI

Investigation Title: Visual Earth Observations

Principal Investigators: Kamlesh Lulla, Ph.D, NASA/Johnson Space Center; Cynthia Evans, Ph.D, and Lev Desinov, Ph.D

Additional Investigators: David L. Amsbury, Ph.D, M. Justin Wilkinson, Ph.D., Julie Robinson, Ph.D., Patricia Dickerson, Ph.D., Joe Caruana, and Kim Willis

INVESTIGATION OBJECTIVES

1. Document environmental changes and dynamic processes on the Earth's surface like flooding and droughts, urban growth and landuse changes around the world, events related to El Niño, and transient features like tropical storms, large fires and volcanic eruptions. Assimilated imagery into the larger database of Earth photographs taken by astronauts and cosmonauts.
2. Use an operational environment to develop approach and tools for ISS-based Earth observations.

PHASE 1 MISSIONS

NASA 2 - NASA 7

OPERATIONAL ACTIVITIES

Use handheld cameras (Hasselblad 70 mm film format with 50, 100 and 250 mm lenses) to photograph Earth's surface over designated regions or over targets-of-opportunity selected by crew or ground-based scientists.

RESULTS

The NASA-Mir missions returned more than 22,000 images of the Earth's surface, taken between March, 1996 and June, 1998. They images have been fully catalogued and added to the Ofiice of Earth Sciences database (http://eol.jsc.nasa.gov).

Specific Mission Results/Highlights

NASA 2: Photos of out-of-control forest fires on the Mongolian Steppes in April 1996; drying reservoirs in the southwest U.S. and northern Mexico during sever drought in western North America; baseline conditions before 1997-98 El Niño

NASA 3: Massive flooding in the lower Nile, continued drought in southern Africa, spring thaw in the southern Andes; baseline conditions before 1997-98 El Niño.

NASA 4: Snow and ice cover over the northern U.S. and Canada, sea ice breakup in Great Lakes and St. Lawrence Seaway. Ohio-Mississippi River floods (March 1997), widespread forest fires in far-eastern Asia (Mongolia, China and Russia) in late April and early May, and detailed imagery of western European river systems (Garonne, Loire, Rhone, Rhine, Danube).

NASA 5: Key atmospheric dynamics related to the developing 1997 El Niño event (thick smoke and haze over South America and Africa).

NASA 6: Continued El Niño observations from September, 1997 through January, 1998, including smoke and haze over Sumatra and New Guinea, dropping lake levels in the high Andes, and key photographs of the unusually lush coast of Somalia after floods.

NASA 7: Continued documentation of El Niño impacts: drought conditions in the central Andes and northeastern South America and Australia, photos of lush vegetation in California, fires and extensive smoke palls in Central America and diminished ice cover in the northeastern U.S.

CONCLUSIONS

Imagery taken from Mir on the joint U.S.-Russian NASA-Mir program is a rich dataset documenting the Earth's dynamic processes over a 2-year time period. It provides a global perspective on the rhythms and spatial scale of important natural and human-induced events occurring on the Earth's surface. Within the context of 35 years of imagery included in the Office of Earth Sciences database, these new observations from the NASA-Mir long-duration missions are changing our understanding of the sizes and frequencies of global processes.

PUBLICATIONS

1. Evans, C. A. , M. J. Wilkinson, J. A. Robinson, S. Runco, P. W. Dickerson, D. L. Amsbury and K. P. Lulla, 1999. NASA Pictures of Earth: The 1997-1998 El Niño: Images of Floods and Drought, Geography Review, V 12. pp 6-9.

2. Kamlesh P. Lulla and Lev Desinov, Cynthia A. Evans, Patricia W. Dickerson and Julie A. Robinson, in press, Dynamic Earth Environments: New Observations from Shuttle-*Mir* missions, Geocarto International, Hong Kong.

Contents

1. C. A. Evans, K. P. Lulla, L. Desinov, N. Glazovskiy, N. S. Kasimov and Yu. F. Knizhnikov, Shuttle-*Mir* Earth Science Investigations: Studying Dynamic Earth Environments from the *Mir* Space Station
2. N. Glazovskiy and L. Desinov, Russian Visual Observations of Earth—Historical Perspective
3. C. A. Evans, J. Caruana, D. L. Amsbury, and K. P. Lulla, Fluctuating Water Levels as Indicators of Global Change: Examples from around the World
4. J. A. Robinson, B.H. McRay and K. P. Lulla, Twenty-Eight Years of Urban Growth in North America Quantified by Analysis of Photographs from Apollo, Skylab, and Shuttle-*Mir*
5. C. A. Evans, J. A. Robinson, M. J. Wilkinson, S. Runco, P. W. Dickerson, D. L. Amsbury and K. P. Lulla, The 1997-1998 El Niño: Images of Floods and Drought
6. M. J. Wilkinson, J. D. Wheeler, R. J. Charlson, and K. P. Lulla, Imaging Aerosols from Low Earth Orbit Using Photographs from Space Shuttle and *Mir*
7. M. J. Wilkinson, K. P. Lulla, and M. Glasser, Biomass Burning and Smoke Palls, with Observations from Space Shuttle and *Mir*
8. P. Saganti, *Mir* Window Survey
9. N. F. Glazovskiy and V. A. Rudakov, Geographical, Geological and Ecological Effects of Caspian Sea-Level Fluctuations—An Introduction
10. P. W. Dickerson, A Caspian Chronicle—Sea-Level Fluctuations between 1982 and 1997
11. L. B. Aristarkhova, A. A. Svitoch and O. N. Bratanova, The Morphological and Geological Structure of the Northern Coast of the Caspian Sea
12. N. I. Alekseevskiy, D. N. Aibulatov and S. V. Chistov, Shoreline Dynamics and the Hydrographic System of the Volga Delta
13. E. A. Baldina, I. A. Labutina, G. M. Rusanov, A. K. Gorbunov and A. F. Zhivoglyad, Changes in Avian Habitats in Volga Delta Wetlands during Caspian Sea Level Fluctuations
14. V. I. Kravtsova and E. G. Myalo, Changes in Coastal Vegetation in the Northern Caspian Region during Sea-Level Rise
15. V. I. Kravtsova, Dynamics of the Northeastern Caspian Coastal Zone in Response to the Rise in Sea Level
16. A. N. Varushchenko, S. A. Lukyanova, G. D. Solovyeva, A.N. Kosarev and A. V. Kurayev, Evolution of the Gulf of Kara-Bogaz-Gol in the Last Century
17. L. M. Shipilova, Eddy Formation in the Caspian Sea

18. E. I. Ignatov and G. D. Solovieva, Geomorphology of Southern Azerbaijan and Coastal Responses to the Caspian Trangression
19. A. S. Shestakov Land-use Changes in the Northwest Caspian Coastal Area, 1978 through 1996--A Case Study of the Republic of Kalmykia

Investigation Title: Visual Observations (VObs)

Principal Investigator(s): Kamlesh Lulla, NASA/Johnson Space Center

Additional Investigator(s): Cythia Evans; Premkumar Saganti; Stanislav Savchenko; Ivan Firsov

INVESTIGATION OBJECTIVES

Not provided by PI

PHASE 1 MISSIONS

NASA 5, NASA 6

OPERATIONAL ACTIVITIES

This experiment was merged with the Visual Earth Observations (Obs) experiment.

Investigation Title: Watershed Hydrologic Studies

Principal Investigators: Thomas J. Jackson, U.S. Department of Agriculture

Additional Investigators: N. Armand, B. Kutuza, A. Shutko, Yu. Tishchenko, B. Petrenko, A. Evtushenko, M. Smirnov, V. Savorskij, I. Sorokin, A. Nikolaev, and A. Sidorenko

INVESTIGATION OBJECTIVES

Regional study to acquire a time series of Priroda satellite observations in conjunction with soil moisture and other important ground and meteorological observations. Results of this part of the investigation were expected to provide important information for algorithm development for future long-term missions involving the AMSR instrument.

PHASE 1 MISSIONS

After only two days of coverage in mid June 1997, the well-known docking accident involving Mir occurred. This resulted in the loss of the Priroda observing system for the duration of SGP97. We were able to acquire two data sets, June 15 and 18, 1997..

OPERATIONAL ACTIVITIES

Data collected during the June 15 and 18, 1997 missions were processed and calibrated by the Russians. The calibrated data products were provided to all cooperators.

RESULTS

A review of the data products provided indicated that many of the passive microwave instruments that we were interested in (primarily the low frequencies) had operating problems. For the channels judged as acceptable a rigorous review and testing of the calibrations was performed. This involved modeling and SSM/I satellite data comparisons over land and water targets with validation data.

CONCLUSIONS

Due to Mir platform problems during the experiment, only a very limited set of data was obtained. Based upon these data, an evaluation of the Priroda sensor performance and some analyses of soil moisture conditions were conducted. These results provide important information for utilizing Priroda data and for soil moisture algorithm development.

PUBLICATIONS

1. Jackson, T. J. , Hsu, A. Y., Armand, N., Kutuza, B., Shutko, A., Tishchenko, Yu., Petrenko, B., Evtushenko, A., Smirnov, M., Savorskij, V., Sorokin, I., Nikolaev, A., and Sidorenko, A., APriroda Passive Microwave Observations in the Southern Great Plains 1997 Hydrology Experiment,@ Proceeding of the Int. Geoscience and Remote Sensing Symposium 1998, IEEE Cat. No. 007803-4403:1568-1570, 1998.

Investigation Title: Cellular Mechanisms of Space Flight-Specific Stress to Plants Experiment

Principal Investigator: Abraham D. Krikorian, State University of New York at Stony Brook

INVESTIGATION OBJECTIVES

1. To use discrete (uniform) somatic embryo fractions at different stages of development to test whether there is a level of development/stage-related element contribution to the observed (chromosome-based) effects.

2. To use somatic embryos which are at the same stage of development but which are of different size and mass to test whether there is a size/mass-related element contribution to the observed (chromosome-based) effects.

3. To use somatic embryos which are cultured on semi-solid medium which is well-drained (dry) versus a more wet semi-solid medium to test whether the water relations of the cells as affected by the prevalence of free water in their immediate vicinity affects the chromosomal (nuclear) responses.

The primary hypothesis for this experiment was that microgravity alters the water and gaseous relations of developing cells that are exposed on nutrient substrates with specific characteristics and water potential in space because the availability and behavior of water in microgravity is significantly different from what it is on Earth. Excess water and accumulation of respiratory gases like carbon dioxide induce a stress in the developing cells and in so doing, aberrant nuclear responses occur as the cell cycle attempts to progress. Persisting changes in plasma membrane-cytoskeleton interface relations is but one aspect of the stress brought on by altered water relations and the resulting hypothesized failure to communicate effectively between cells in developing systems is reflected in many changes, including imperfections in chromosomal movement and division.

What this amounts to is the following: A picture is emerging that a space environment-specific stress can be delivered to plant cells and tissues. The stress is most severely experienced by cells and tissues that are vulnerable due to their size, stage of development and growing environment. On this view, smaller and less developed embryogenic units are more vulnerable than those that are larger. Units that are more larger and more advanced in terms of their progression are less sensitive than those that are just beginning progression of their development. Embryogenic units that are in an optimal growing environment so far as their continued development is concerned are less perturbed than those than are in a less optimal environment.

All this may be reduced to 'Space-specific stress as related to environmental parameters and cell and developmental complexity" hypothesis

Stated yet another way, the main objective of the work detailed in this report was: (1) to characterize and refine our understanding of stress to plant cells in the space environment in the novel context of its relationship to, indeed the very basis of the expression and progression of somatic embryogenesis in totipotent cultured plant cells.

Equally important, and indeed more important in the long run was to ascertain whether the kinds of abnormalities of cytology encountered in other missions have biological significance. That is to say, if chromosomal abnormalities are encountered, do they persist, and if so, what is the consequence of their persistence.

A well-defined somatic cell system from daylily provided the test materials.

PHASE 1 MISSIONS

NASA 4

OPERATIONAL ACTIVITIES

Not provided by PI.

RESULTS

Poor growth and nuclear abnormalities observable in some space-grown plants has been hypothesized as due to a combination of factors such as biological status, the specific way they are grown and the way they experience multiple stresses, some of which are space-specific. Data from a 132 day experiment on 'Mir' using embryogenic cell cultures of daylily allows us to harmonize seemingly contradictory evidence.- a) the more developed an embryo the less likely it is to suffer catastrophic cell stress during growth; the less developed, the greater its vulnerability; (b) the extent to which the stress becomes manifest is also dependent on the extent of pre-existing stresses imposed by suboptimal growing conditions; (c) an appropriate albeit undesirable "stress match" with other non-equilibrium determinants, much like a 'tug of war', can result in genomic variations in space.

CONCLUSIONS

Fastidiously-controlled growing environments for plant cells must be devised if one is to resolve the matter of direct versus indirect effects of space. Acces to 1 G centrifuges must be an important parameter in these experiments. On a practical level, it is predicted that adapting plant biotechnologies to space conditions will not be a casual matter.

PUBLICATIONS

1. Krikorian, A. D. (1997) Plant cells in space: what have we learned? Gravitational and Space Biology Bulletin 11 (no. 1): 3.
2. Krikorian, A. D. (1998) Plants and Somatic Embryos in Space: What Have We Learned? American Society for Gravitational and Space Biology Bulletin 11(no.2): 5-14.
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5. Krikorian, A. D. 1998. Plant somatic embryos in space. In: 32nd Scientific Assembly of COSPAR 12-19 July 1998. Nagoya, Japan. p. 380.
6. Krikorian, A. D. (199?) Somatic embryos of daylily in space. 32nd COSPAR Scientific Assembly (Nagoya, Japan) (accepted)

Investigation Title: Developmental Analysis of Seeds Grown on Mir

Principal Investigator(s): Mary E. Musgrave, Ph.D., Louisiana State University; Dr. Rita Levinskih, Institute of Biomedical Problems

Additional Investigators: Dr. Gail Bingham and Dr. Greg Briarty

INVESTIGATION OBJECTIVES

1. Analyze space flight effects on plant growth and development processes throughout the life cycle through inflight observations, video recording, gas exchange measurements, and postflight analysis of plant material harvested and fixed, dried or frozen on orbit.

2. Collect seed produced on orbit and grow this seed to produce new plants, comparing the production of seeds by plants from space-produced seeds to that of plants from ground-produced seeds. Seed will also be studied extensively postflight and compared with ground controls and with seed produced during space flight by the plants grown from space-produced seeds.

3. Analyze floral initiation and early reproductive development during space flight, comparing plants from seeds produced on the ground, in space, or by plants grown from seeds produced in space.

4. Evaluate the extent of space flight influence on cell shape in plant organs, and assess the implications on overall metabolism.

5. Determine the extent of space flight-mediated changes in cell structure, organization and physiology.

6. Analysis of the root medium in the Svet Root Modules.

7. Analysis of the microbial organisms present on plant tissue and in the root medium.

PHASE 1 MISSIONS

Mir 24/NASA 5

OPERATIONAL ACTIVITIES

This experiment addressed the problem of seed-to-seed cycling in microgravity, using the species Brassica rapa, a mustard plant with a very short life cycle. The experiment called for 3 consecutive plantings of Brassica, beginning with seeds launched from the ground on STS-84. These were the so-called "Earth seeds", or E1 seeds. Seeds produced in space from this first planting on Mir were collected, dried, and used in the second growth cycle. This second set of seeds was called "Space 1", or S1 seeds. Seeds generated in space from the second planting on Mir, the S2 seeds, were collected and planted in the third planting in space, along with Earth seeds and S1 seeds. Surplus seeds produced by the plants during the first two growing cycles were used to supply dried material for postflight analysis, as well as seeds for subsequent planting in Svet. Additional developmental and physiological information was obtained from fixed plant samples obtained during the growing cycles, from dried plants taken at final harvest stages, and from plants freshly harvested and frozen at the end of the third planting.

RESULTS

This investigation was the first to successfully investigate growth of plants over multiple generations in space. It showed that for the model plant (Brassica rapa):

1. Vegetative growth, flowering, and reproductive development was comparable in microgravity to that observed in the ground control. No stage of the plant life cycle is dependent upon gravity for its completion. Seeds were produced in space, and these seeds were re-planted and grew into new plants.

2. The growth characteristics of the plants in microgravity were highly reproducible, resulting in comparably sized plants in the three growth cycles. Reproducing aspects of the space flight environment in the ground control (carbon dioxide, ethylene, humidity, light, temperature) resulted in plants that did not differ significantly in size and developmental rate from those grown on orbit.

3. The quality of the seeds produced in space was lower than in the ground control. This led to smaller second generation plants in the space flight treatment.

4. The ripening process inside maturing seed pods occurs differently in microgravity, probably due to indirect effects of microgravity on the gaseous microenvironment around the developing seeds.

5. The ability of plants to grow and reproduce in microgravity has been confirmed in this experiment. Further studies with different species will be necessary to determine if reduced seed quality would be a general concern during space flight, or is a factor associated only with this particular plant type and seed pod architecture.

Status of Data Received/Analyzed

Initial analysis of data collected on dried and fixed material during postflight procedures has been completed and a preliminary report has been submitted to a scientific journal for review. The postflight ground control is complete. Processing of both sets of samples is proceeding.

CONCLUSIONS

The Greenhouse 3 experiment has provided a wealth of information and material for future study. The experiment design allowed us to depart from the past practice of comparing space flight plants only to ground-based controls, since reference plants (produced from seed that had been brought from Earth) were grown alongside the second generation space plants for comparison purposes. Growth and reproductive effort by reference plants grown from Earth seeds was comparable in the three growth cycles. In the two growth cycles utilizing first generation space seeds, plants were smaller and produced fewer flower buds than reference plants grown from Earth seed on orbit at the same time.

Following the completion of the high-fidelity postflight ground control, we have understood that ethylene gas on the Mir station was a primary determinant of plant size. The results of analyses completed to date indicate no significant differences between space flight and ground control material in first generation plants. However, second generation space plants were significantly smaller than second generation ground control plants. Our data indicate that the quality of seeds produced on orbit is lower than that of seeds produced in the ground control, thus leading to the smaller second generation plant size. The weight per seed of seeds produced on orbit was significantly lower than that of seeds produced in the postflight ground control. We believe that this diminished seed quality is due to different ripening kinetics inside the seed pod in microgravity. Further investigations with the dried seeds as well as the fixed and frozen plant material may provide additional information about the nature of reduced growth by the plants from first generation space seeds.

PUBLICATIONS

1. Musgrave, M. E., A. Kuang, Y. Xiao, G. E. Hingham, L.G. Briarty, M.A. Levinski, V. N. Sychev and I. G. Podolski. 1998. Repeated seed-to-seed experiments with Brassica rapa on the Mir Space Station. Gravitational and Space Biology Bulletin 12: 56.

2. Bingham, G. E., S. B. Jones, D. Or, I. Podolsky, V. Sytchev. 1998. Water management lessons from plant full life cycle experiments on Mir. Gravitational and Space Biology Bulletin 12: 56.

Investigation Title: Effective Dose Measurements at EVA

Principal Investigators: Sandor Deme, Ph.D., KFKI Atomic Energy Research Institute; Yuri A. Akatov

Additional Investigators: Istvan Apathy and Istvan Hejja

INVESTIGATION OBJECTIVES

Development of an on-board TLD (thermoluminescent dosimeter) system to provide:

1. High sensitivity dose measurement to gain information on extra doses during extravehicular activity.
2. Measurement of ratio of low LET (linear energy transfer) to high LET dose components inside the Mir Space Station.

PHASE 1 MISSION

NASA 4, NASA 5

OPERATIONAL ACTIVITIES

Dislocation of TL (thermoluminescent) dosimeters inside Mir and periodical their readouts by US astronaut. One dosimeter was used as a personal dosimeter, two dosimeters were used during EVA

RESULTS

The dose rate range inside Mir measured by TLD method was in range 9.3...18.3 μGy/h, the EVA dose rate was about 3 times higher then the mean dose rate inside Mir. The ratio of high LET radiation induced TLD peak was about 1.4 times higher than for calibration gamma-radiation source

CONCLUSIONS

The dose rate measured with the individual dosimeter of the astronauts was significantly lower than the mean value of other three dosimeters located in the working area and sleeping cabin.

PUBLICATIONS

1. S. Deme, I. Apathy, I. Hejja, E. Lang and I. Feher: Extra Dose due to EVA during the NASA4 Mission, Measured by an On-Board TLD System. To be published in Radiation Protection Dosimetry in 1999.

Investigation Title: Effects of Gravity on Insect Circadian Rhythmicity

Principal Investigators: Tana M. Hoban-Higgins, Ph.D., University of California at Davis; Alexei M. Alpatov, Institute of Biomedical Problems

Additional Investigators: Gary T. Wassmer and Charles A. Fuller

INVESTIGATION OBJECTIVES

1. To study the long-term effects of altered gravitational environments on the Circadian Timing System of insects

PHASE 1 MISSIONS

NASA 5

OPERATIONAL ACTIVITIES

Collection of activity data from 64 individual beetles under different lighting conditions.

RESULTS

Entrainment (synchronization) of the activity rhythms to light-dark cycles. Free-running activity rhythms in both constant light and constant darkness. Resetting of the circadian clock by light pulses against a background of constant darkness.

CONCLUSIONS

It is possible to induce both phase advances and delays in the microgravity space environment. Light intensity affects the period of the circadian clock in the microgravity space flight environment.

PUBLICATIONS

1. Hoban-Higgins, T. M., A. M. Alpatov, T. Schnepp, P. Savage, E. Hayward, G. Fenton, M. Hale, J. Higgins, S. Piert, G. T. Wassmer and C. A. Fuller. Beetles in space

long-term monitoring of insect circadian rhythms on NASA-Mir. ASGSB Bulletin 10 (1): 66, 1996.

2. Hoban-Higgins, T. M. Body Clocks in Space. Invited talk at American River College for National Science and Technology Week. April, 1996.
3. Hoban-Higgins, T. M., A. M. Alpatov, G. T. Wassmer, W. J. Reitveld and C. A. Fuller. Response of insect activity rhythms to altered gravitational environments. J. Grav. Physiol 4(2): 109-110, 1997.
4. Hoban-Higgins, T. M. Gravitational biology on Mir. J. Grav. Physiol., Invited paper, in press, 1998.
5. Alpatov, A. M., T. M. Hoban-Higgins, C. A. Fuller, A. O. Lazarev, W. J. Rietveld, V. B. Tschernyshev, E. G. Tumurova, G. Wassmer, V. A. Zotov. Effects of microgravity on circadian rhythms in insects. J. Grav. Physiol., Invited paper, in press, 1998.

Investigation Title: Environmental Radiation Measurements on Mir Space Station

Principal Investigator: Eugene V. Benton, Ph.D., University of San Francisco

Additional Investigators: Eric Benton, Allen Frank, and Vladislav Petrov

INVESTIGATION OBJECTIVES

Not provided by PI.

PHASE 1 MISSIONS

NASA 2 - NASA 5

OPERATIONAL ACTIVITIES

Deployment and retrieval of internal Area Passive Dosimeters.

Deployment and retrieval of External Dosimeter Array.

RESULTS

40% Variation in Dose measured as a function of location/shielding inside Core Module.

Three order of magnitude decrease in dose as a function of shielding within the first g/cm^2 as measured on the outside of Mir.

Significant contribution to LET spectra >5 keVμm from proton-induced target fragment secondaries.

CONCLUSIONS

Dose varies significantly as a function of shielding within spacecraft.

Astronauts will receive significantly greater dose during EVA inside the South Atlantic Anomaly.

Proton-induced target fragmentation must be considered as one of the principle sources of dose and dose equivalent to astronauts inside spacecraft.

PUBLICATIONS

Currently being written.

Investigation Title: Greenhouse - Integrated Plant Experiments on Mir

Principal Investigator(s): Frank B. Salisbury, Ph.D., Utah State University; Margarita Levinskikh, Ph.D., Institute of Biomedical Problems

Additional Investigators: Dr. Gail Bingham, Dr. William F. Campbell, Dr. John G. Carman, and Dr. David Bubenheim

INVESTIGATION OBJECTIVES

1. To investigate the effects of microgravity on the productivity of a crop plant, specifically dwarf wheat.
2. To identify the chemical, biochemical, and structural changes in plant tissues induced by microgravity.
3. To determine microgravity's effect on plant processes, such as photosynthesis and water use.
4. To evaluate current facilities for plant growth aboard the Mir.

PHASE 1 MISSIONS

Mir 19, Mir 20, Mir 21/NASA 2, Mir 22/NASA 3

OPERATIONAL ACTIVITIES

The first two seed plantings of wheat occurred during Mir 19. Plant development was monitored by daily observations and photographs taken by the Mir 19 crew. Although the plants grew for almost the entire 90 days of the experiment, failure of four of the six fluorescent lamp sets resulted in low lighting. The low lighting levels and low moisture content in the root module resulted in poor growth of the plants. However, plant samples and equipment were transferred to and brought back to Kennedy Space Center by STS-74, where they were divided among U.S. and Russian investigators for further analysis. A new set of wheat seeds was planted about midway through the Mir21/NASA2 mission. Plant development was monitored by daily observations, photographs and video taken by the crew. The final harvest of the plants that were planted during Mir 21 (known as the seed-to-seed experiment) occurred during the docked phase of the STS-81 mission. The second crop planting, which was originally scheduled to occur during the Mir22/NASA3 mission, was not performed. Fixed samples from the seed-to-seed experiment were returned to Earth for analysis on the STS-81 flight. The Svet/Greenhouse hardware was dismantled and stowed on the Mir until its next usage during the NASA 5 mission.

RESULTS

The overall goal of this work has been to understand the nature of the disruption of reproductive events by microgravity. During this study, we have greatly advanced the understanding of this problem. Specifically, we have shown that properly designed instrumentation and experiment management can provide the environmental data necessary to document the stresses experienced by the experimental crop. These data can exclude many of the possible causes of differences observed between ground and space grown plants. Second, we have shown that we can measure real-time plant transpiration and gas exchange. These data, telemetered to Earth on a daily basis could allow experiment managers to monitor nondestructively (no harvests) the development of plants growing in microgravity on a daily basis. This is the first time that such data have ever been collected in space. Third, we have shown that significant differences exist between the water relations of wet porous substrates in microgravity and on Earth. These differences must be monitored and accounted for to produce healthy plants. The Greenhouse IIb experiments demonstrate that we now have both the knowledge and instrumentation to provide a good plant root environment. Without the models and instrumenta-tion developed in this experiment, this would not be possible.

Status of Data Received/Analyzed

Plant and substrate samples were shipped postflight to US and Russian Investigators. All samples were received in the PI Laboratories in excellent condition. Approximately 70% of the light (LM), SEM, and confocal laser scanning optical microscopic (CLSOM) analyses are complete. However, transmission electron microscopy (TEM) is only about 20% completed. It is anticipated that 90% of the TEM work will be completed by December 31, 1998. Data analysis to date shows that it is very important to conduct a gas exchange ground experiment to provide a comparison with the crop canopy uptake and the old crop root respiration rates that we have measured in space. An experiment to measure these rates is now being prepared. Once these data have been collected, the gas exchange data will be ready to publish.

CONCLUSIONS

There were several potentially important results from the NASA 3 Greenhouse 2 experiment. For example, biomass production during the 123-d growth period far exceeded that of any other comparable experiment with plants in space, which suggests that plant growth is not adversely affected by microgravity. This phenomenon was again indicated in the second planting, which was harvested after 30 d and returned in the GN2 freezer. Upon final harvest and return to Earth, the most interesting observation was the lack of seeds in the many wheat heads that were produced; we experienced 100% floret sterility.

All the data received from the NASA 3 Greenhouse 2 experiment have been reviewed. The quality of most of the data collected on the hard drives is excellent. This is the first mission where appreciable downlinking support from MIPS was available. Some data files that can be used to calculate photosynthesis were collected. Two data files that will be used to determine respiration in darkness were also collected. Soil moisture data collected during the mission is of good quality and will provide an excellent basis for a paper about the problems encountered with porous substrates in microgravity.

PUBLICATIONS

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2. Salisbury, F. B., G. E. Bingham, W. F. Campbell, J. G. Carman, D. L. Bubenheim, B. Yendler and G. Jahns. 1995. Growing super-dwarf wheat in Svet on Mir. Life Support and Biosphere Science 2:31-39.

3. Bingham, G. E., S. B. Brown, F. B. Salisbury, W. F. Campbell, J. G. Carman, G. Jahns, D. Pletcher, D. B. Bubenheim, B. Yendler, V. Sytchev, M. A. Levinskikh, I. Podolsky, I. Ivanova, P. Kosgtov and S. Sapunovca. 1996. Environmental measurements observed during the greenhouse-2 experiment on the Mir orbital station. COSPAR 31:364.

4. Bingham, G., F. Salisbury, W. Campbell, J. Carman, B. Y. Yendler, V. S. Sytchev, Y. B. Berkovich, M. A. Levinskikh and I. Podolsky. 1996. The spacelab-Mir-1 "Greenhouse-2" experiment. Adv. Space Res. 18:225-232.

5. Salisbury, F. B., W. F. Campbell, J. Carman, G. Bingham, D. L. Bubenheim, B. Yendler, V. Sytchev, M. A. Levinskikh, I. Ivanova, L. Chernova and I. Podolsky. 1996. Plant growth during the greenhouse II experiment on the Mir orbital station. COSPAR 31:364.

6. Gillespie, L. S., F. B. Salisbury, W. F. Campbell and P. Hole. 1996. Why were Super-Dwarf wheat plants grown in Space Station Mir vegetative: Heat shock, short day, or microgravity? ASGSB Bulletin 10:74.

7. Salisbury, F. B., G. E. Bingham, W. F. Campbell, J. G. Carman, P. Hole, L. S. Gillespie, V. N. Sytchev, I. B. Podolsky, M. Levinskikh, D. L. Bubenheim and B. Yendler. 1996. Experiments with Super-Dwarf wheat in Space Station Mir. ASGSB Bulletin 10:34.

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Investigation Title: Incubator - Effects of Weightlessness on the Avian Visuo-Vestibular System: Immunohistochemical Analysis

Principal Investigator: Toru Shimizu, Ph.D., University of South Florida

INVESTIGATION OBJECTIVES

The purpose was to study the fundamental effects of gravity deprivation on the visuo-vestibular system of Japanese quail Coturnix coturnix japonica. In particular, the distributions of various neurochemicals during development were analyzed by using immunohistochemical techniques. Development of the visual brain was also studied by measuring the volumes of the structure called the optic tectum.

PHASE 1 MISSIONS

NASA 2

OPERATIONAL ACTIVITIES

Quail eggs were launched on a Space Shuttle (STS-76) and placed into the on-board Mir incubator. On specified days, eggs were removed from the incubator and shells were cracked in a plastic bag filled with a fixative solution of 4% paraformaldehyde. All bags were stored at ambient temperature until returned on a Space Shuttle (STS-79). The fixed eggs (embryos) were shipped to Ames Research Center for dissection by the Russian and U.S. PIs.

The PI analyzed the forebrains of 4 embryos from the flight group (2-E16s and 2-E14s) and compared them with samples from the ground-based control group. Tissues were frozen, cut in a cryostat, and processed with antibodies against 14 neurochemicals, which are known to exist in the avian and mammalian visuo-vestibular systems.

RESULTS

1) For the samples which had adequate fixation, the results showed relatively consistent staining patterns for several neurochemicals, such as a calcium-binding protein (CB) and an enzyme for acetylcholine, which are important markers for avian sensory development. Although the positive staining was already visible in the visuo-vestibular system of the E14s and clearly detected in the E16s of the flight group, the number of stained cells appeared to be fewer, and the staining was more faint, than stained cells in the control group. 2) The avian optic tectum is the major retinorecipient structure with well-developed laminations. These layers were clearly stained with Nissl staining in all groups. Portions of the optic tectum of some samples were either damaged or detached due to an incomplete fixation, and thus no accurate measurement was possible for these samples. With the collaboration of Dr. Dmitri Lytchakov (Sechenov Institute of Evolutionary Physiology and Biochemistry, Russian Academy of Sciences), a few cases were observed with an abnormal development of the eyes and optic tectum under the microgravity condition. For instance, there were cases with retarded or asymmetrical development of the eyes and tectum.

CONCLUSIONS

These results indicate that microgravity significantly affects the embryogenesis of the avian brain in terms of morphology and chemistry. The number of subjects and tissue fixation methods need to be improved to confirm these observations.

PUBLICATIONS

1. Shimizu, T. (1997). Effects of weightlessness on the avian visuo-vestibular system: Immunohistochemical analysis. NASA Technical Memorandum, 66-67.
2. Bower, A. N. & Shimizu, T. (1998). Effects of weightlessness on the avian visuo-vestibular system: Immunohistochemical analysis. NASA 1st Annual Partners in Research and Education Conference.

Investigation Title: Incubator - Effects of Weightlessness on Vestibular Development of Quail

Principal Investigator: Bernd Fritzsch, Ph.D., Creighton University

Additional Investigators: Laura L. Bruce, Ph.D.

INVESTIGATION OBJECTIVES

1. To examine the central projection from gravistatic receptors (utricle and saccule) into the brainstem in quail raised in zero gravity from egg laying to approximately hatching (17 days) and to compare these results with those from synchronously incubate eggs and control groups.

2. To examine the peripheral termination of vestibular fibers at the gravistatic receptors within the sensory epithelia and to compare these results with those from control quail.

PHASE 1 MISSIONS

Flown on Mir, total of three flights, only one flight (Atlantis) resulted in some successfully incubated quail eggs.

OPERATIONAL ACTIVITIES

Not provided by PI.

RESULTS

In the absence of a fixation suitable for DiI tracing, we tried to analyze the ears using immunohistochemical techniques. Initial stains indicated in control quail that we would be able to label the nerve fibers using an antibody against β-acteylated tubulin. However, using this antibody we did not get any staining in the microgravity expose ears. Again, the insufficient fixation is likely to blame. As a last resort we embedded the ears in plastic for a thick section analysis of hair cell numbers and degree of maturation. Unfortunately even this rather simple issue could not be analyzed in the microgravity-exposed chicken due to inadequate fixation. Both the incubator and the fixation technique are currently being revised by NASA.

CONCLUSIONS

The data confirm previous findings that quail embryos can, under proper circumstances, develop until hatching in microgravity. There were no gross abnormalities in the few ears of the late embryos (we received 3 ears at E14.5 and 4 ears at E16.5). Due to inadequate numbers of samples returned and their fully insufficient fixation, no conclusions could be reached that warrant any publications.

PUBLICATIONS

1. Bruce, L.L. and Fritzsch, B. (1997) The Development of Vestibular Connections in Rat Embryos in Microgravity. J. Gravit. Physiol. Vol. 4: 59-62.

2. Fritzsch, B. (1998) Evolution of the Vestibulo-Ocular system. Otolaryngology - Head and Neck Surgery, 119: 182-196.

3. Fritzsch, B. (1998) Of mice and genes: Evolution of vertebrate brain development. Brain, Behav. Evol., 52: 207-217.

Investigation Title: Incubator - Expression of Contractile Proteins in Microgravity

Principal Investigator: Page A. Anderson, M.D., Duke University Medical Center

INVESTIGATION OBJECTIVES

The study of the effects of microgravity on troponin T and troponin I isoform expression in the quail.

PHASE 1 MISSIONS

SLM-1 Incubator II

OPERATIONAL ACTIVITIES

Dissected fixed hearts from embryonic quail of a range of developmental stages in ovo from control groups and flight groups. Harvested RNA from the hearts. Performed RT-PCR to assess ability to obtain cDNA from fixed tissue and to develop primers to examine relative expression of two troponin T isoforms expressed in the quail in ovo.

RESULTS

We successfully purified RNA from fixed embryonic cardiac tissue in amounts sufficient for us to perform RT-PCR experiments. We obtained two PCR products using primers based on rabbit cardiac troponin T (cTnT) cDNA. The sequences from an alternatively spliced region and that from a central highly conserved region were of the appropriate size. One of the two RT-PCR products was a quail sequence. We have subsequently used primers from highly conserved regions of cardiac troponin T cDNA. These primers were successfully used to obtain a quail cardiac troponin T cDNA sequence that lacks the 5' region. This quail cardiac troponin T sequence has not been previously described. Rare cDNA from the human heart suggested the potential for splicing in the central highly conserved region of the molecule. The cDNA, we obtained from the quail heart, supports the presence of such splicing.

CONCLUSIONS

Our modification of previously published methods for obtaining RNA from fixed tissues results in a markedly greater yield of transcript. RT-PCR of quail cardiac RNA has yielded a novel product. It lacks sequences from two central exons, similar to a rare human cardiac troponin T cDNA. The new splicing pattern may have functional consequences. If such cDNA are translated, the resultant proteins would lack regions thought to be important in the interaction of the proteins that regulate cardiac contractions. The protocols developed in this investigation will prove useful in studying gene regulation in microgravity. The stability of RNA in fixed tissues allows fixing of solid tissue and blood in microgravity and subsequent analysis many months and potentially years after the tissue was harvested. Thus, gene expression and its modification by microgravity can be examined over time in the adult and during development in the embryo and fetus. Our findings may be important in understanding protein-protein interaction that regulates cardiac contraction.

PUBLICATIONS

Not provide by PI.

Investigation Title: Incubator - Hypogravity's Effect on the Life Cycle of Japanese Quail

Principal Investigator: Patricia Y. Hester, Ph.D., Purdue University

Additional Investigators: Joseph I. Orban, Steven J. Piert, and Tamara Guryeva

INVESTIGATION OBJECTIVES

A series of studies were conducted to determine the effect of activities preceding space flight and during space flight on the use of calcium from the shell of developing quail.

PHASE 1 MISSIONS

NASA 2

OPERATIONAL ACTIVITIES

Quail eggs were subjected to preflight dynamics, centrifugation, vibration, or a combination of vibration & centrifugation prior to incubation.

Quail eggs (48) were launched on the Shuttle and incubated in a Slovakian incubator on Mir.

Development was stopped on 3, 7, 10, 14, & 16 d of incubation.

RESULTS

Preflight activities & dynamics had no effect on the quail embryo's survivability or their ability to utilize calcium from the shell.

Calcium utilization was impaired in embryos incubated in microgravity when compared to ground laboratory controls.

CONCLUSIONS

Calcium utilization was impaired in quail embryos incubated in microgravity. It was not clear if this impairment was due to factors other than microgravity.

PUBLICATIONS

Abstracts

1. Hester, P. Y., and K. Boda, 1997. Egg rotation during avian embryogenesis. Am. Soc. Gravitat. Space Biol. 11:28.
2. Orban, J. I., and P. Y. Hester, 1998. Calcium uptake by quail embryos incubated in space. Am. Soc. Gravitat. Space Biol. 12: 48.
3. Hester, P. Y., J. I. Orban, S. J. Piert, T. Gurieva, A. L. Wentworth, and B. C. Wentworth, 1998. Effect of preflight activities and launch dynamics on avian embryogenesis. Am. Soc. Gravitat. Space Biol. 12:64.

Journal Articles

4. Orban, J. I., S. J. Piert, T. S. Guryeva, and P. Y. Hester, 1999. Calcium utilization by quail embryos during activities preceding space flight and during embryogenesis in microgravity aboard the orbital Space Station, Mir. FEBS Letters (submitted).
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Investigation Title: Incubator - Skeletal Development in Long-Duration Space Flight

Principal Investigator: Stephen B. Doty, Ph.D., Hospital for Special Surgery

INVESTIGATIVE OBJECTIVES

This flight experiment was to study the bone formation and skeletal development during embryogenesis which was occurring in space. This would permit distinctions between purely genetically driven processes (e.g. Mesenchymal condensations, cartilage analage formation, etc.) and mechanically or environmentally driven events (e.g. Bone remodeling, cell replacement, etc.). The Specific Objectives were: (1) Use physical measurements of wing and leg size to determine gross limb and skeletal development. (2) Measure areas of mineralization by image analysis and x-ray microanalysis in limbs and flat bones during different stages of development. (3) Use electron microscopy to evaluate mineral deposition within collagen matrix and compare this to the distribution of alkaline phosphatase activity (an enzyme necessary for mineralization to occur). (4) Use immunocytochemistry to localize and compare the different distribution of collagen types in cartilage and bone. (5) Compare the development of flat bones with the long bone development since they are formed by different mechanisms and may be affected differently by space flight.

PHASE 1 MISSIONS

NASA 2

OPERATIONAL ACTIVITIES

Random bred quail eggs (Coturnix coturnix japonica) were obtained from University of Wisconsin (Dr. Wentworth) and shipped to KSC where they were weighed, numbered and candled. They were placed into the RSKE with an ATR-4 to monitor temperature. The RSKE was placed into the CRIM and monitored until turnover. Launch was on 3/22/96 (STS-76) to carry the eggs to Mir. Inflight fixations occurred on Mir, corresponding to embryonic days 0, 3, 7, 10, 14, and 16. Fixed eggs were returned on STS-79, and Russian and US PIs carried out tissue dissections on these embryos at ARC. There were appropriate Synchronous and Laboratory Controls available for dissection at the same time.

RESULTS

There was no measurable difference in leg length or wing length at any embryonic age, comparing Flight and Controls. Morphometric measurements of cartilage and bone content of the long bones does suggest a delay in conversion of cartilage to bone in flight animals at embryonic day 10, but this was not evident at later development times. In the mandible, x-ray microanalysis of Ca and P content of the bone matrix showed a reduced content of these bone minerals at day 10, but no differences at later embryonic age. Electron microscopy showed a reduced bone matrix and reduced mineralization in the earliest developing embryos (embryonic days 7 & 10) at the cartilage/bone interface of the tibias. But the fixation of the older embryos was too poor to permit any meaningful electron microscopy. Staining for matrix proteins has not been helpful because all samples indicate a normal distribution of matrix (e.g. Collagen type I, II, and X; proteoglycans and fibronectin). We have started staining for Proliferating Cell Nuclear Antigen, cyclin D, and ubiquitin as indicator of changes in cell cycle or cell proliferation in cartilage and bone. This latter procedure was not included in the original grant but during this study, it became apparent that any changes during embryogenesis will have to occur very early in development and therefore cell differentiation, proliferation and cellular apoptosis may be better areas of study.

CONCLUSIONS

We have found good evidence that very early bone formation and mineralization appear to be delayed during embryogenesis. This occurred in the flat bones (mandible) and long bones (tibia) so the effect due to space flight is not confined to endochondral bone formation (i.e. conversion of cartilage to bone). However, it becomes very difficult in studies of this type to determine whether the bone cartilage in these older embryos and visually it becomes impossible to determine whether any of these processes have been slowed. In the early embryos, the appearance or lack of appearance of mineral is easily determined. Also, the fixation of the older embryos was quite poor, probably due to the thickened epidermis and feathers which inhibit penetration of fixative into the deep tissues, such as bone. This precluded any electron microscopy which could have provided more detailed analysis of the collagen matrix and its mineralization. In like manner, the immunostaining of matrix proteins by light microscopy is not sensitive enough to determine whether very slight changes in matrix have occurred, which is probably the case for this study. With our ongoing analysis of looking for proliferating cells (stained for proliferating cell nuclear antigen), cell apoptosis and cell cycling, we may find changes in cellular differentiation which will provide clues as to how and where cell activity was decreased during space flight.

PUBLICATIONS

Not provided by PI.

Investigation Title: Standard Interface Glovebox Hardware Verification

Principal Investigator(s): Paul D. Savage, NASA/Ames Research Center

Additional Investigators: N/A

INVESTIGATION OBJECTIVES

Perform functional verification procedures to ensure proper containment for investigations utilizing the Standard Interface Glovebox Operations.

The objectives of the experiments/investigations will be reported in their own individual reports. The MGBX project does not attempt to report on the science objectives associated with the different investigation conducted in the facility. However, the objective for the MGBX facility is to provide a common facility that represents one or two levels of containment, so that the investigation teams can focus on development of flight hardware to obtain the desired science and minimize the need to meet the containment issues associated with manned space flight.

PHASE 1 MISSIONS

NASA 2 - NASA 5

OPERATIONAL ACTIVITIES

The SIGB was successfully installed in its location in Priroda. Following the performance of the functional verification procedure, the SIGB was found to be fully operational.

RESULTS

The MGBX facility has operated flawlessly during the 290 hours of accumulated time through NASA 4. The facility is working as designed.

Status of Data Received/Analyzed

The NASA 4 investigation data has been reduced and supplied to the respective teams.

CONCLUSIONS

The Mir Glovebox (MGBX) for Microgravity Investigations is a facility located in the Priroda module of the Mir Space Station. The facility provides a work area for microgravity investigations that can be physically isolated from the manned environment. In addition, the facility can provide a negative pressure in the physically isolated work area with respect to the manned environment using an air filtration system that is closed (isolated from the manned environment) as long as no leaks occur in the physical isolation system. This air circulation system represents a second level of containment in that nothing can get from the work area into the manned environment without passing through two separate banks of filters. The filters are capable of capturing all solid particulate (>3 microns in diameter) and liquids.

PUBLICATIONS

N/A

Investigation Title: Analysis of Volatile Organic Compounds on Mir Station

Principal Investigator: Peter T. Palmer, Ph.D., San Francisco State University

Additional Investigator: Warren Belisle

INVESTIGATION OBJECTIVES

1. Characterization of volatile organic compounds (VOCs) in Mir air samples using both proven gas chromatography/mass spectrometry (GC/MS) and new direct sampling ion trap mass spectrometry (DSITMS) techniques.

PHASE 1 MISSIONS

Mir 19, Mir 21 - Mir 25

OPERATIONAL ACTIVITIES

Collection of air samples using both grab sample containers (GSCs) and solid sorbent air sampler (SSAS).

RESULTS

Documentation of VOC types and concentrations on Mir; development and validation of new technology for air quality monitoring.

CONCLUSIONS

Mir air quality meets NASA specifications; DSITMS technology shows promise as sensitive, selective means for real-time air quality monitoring for life support applications.

PUBLICATIONS

1. P.T. Palmer, C.M. Wong, R.A. Yost, N.A. Yates, and T.M. Griffin, "Advanced Automation for Ion Trap Mass Spectrometry - New Opportunities for Real-Time, Autonomous Analysis", in Artificial Intelligence Applications in Chemistry, S. Brown (Ed.), Wiley, 1996, pp. 25-60.
2. P.T. Palmer, X. Fan, C. Remigi, B. Nies, and L. Lee, “Direct Sampling Ion Trap Mass Spectrometry – A Growing Toolkit for Air Monitoring Applications”, SAE technical paper series 981743.
3. P.T. Palmer, D. Karr, and Carla Remigi, “Evaluation of Two Different Direct Sampling Ion Trap Mass Spectrometry Methods for Monitoring Volatile Organic Compounds in Air”, Journal of the Field Analytical Chemistry and Technology, manuscript submitted.

Investigation Title: Anticipatory Postural Activity (Posa)

Principal Investigator(s): Charles S. Layne, Ph.D., KRUG Life Sciences, Inc.; Inessa B. Koslovskaya, M.D.

Additional Investigators: Jacob J. Bloomberg, Ph.D., P. Vernon McDonald, Ph.D., and Andrei A. Voronov, Ph.D.

INVESTIGATION OBJECTIVES

1. Determine how long-duration space flight alters the anticipatory neuromuscular activity associated with arm movement.

2. Perform proof-of-concept research to determine whether foot sensory input modifies neuromuscular responses during space flight.

3. Determine the time course of adaptation during long-duration space flight to foot sensory input as measured by patterns of neuromuscular activation.

4. Determine whether long-duration space flight modifies anticipatory neuromuscular postural activity in the immediate postflight period.

5. Determine whether modifications in anticipatory neuromuscular postural activity associated with long-duration space flight are correlated with postural instability immediately after landing and during the recovery period.

PHASE 1 MISSIONS

Mir 21/NASA 2

OPERATIONAL ACTIVITIES

During all ground-based data collection, subjects wore shirts, T-shirts and stocking feet with electrodes and accelerometer leads attached to the body with adhesive tape (Belt Pack Amplification System (BPAS) vest assembly). An accelerometer was attached to a wrist splint worn by the subject. The subject stepped onto a force plate, assumed an upright position with feet shoulder-width apart and arms resting comfortably at the sides. With eyes closed, the subject performed 15 rapid, 90-degree shoulder flexions, keeping the arm and wrist locked throughout the movement. The movements were self-initiated and the subject regained stability before performing the next movement. The Flock of Birds motion analysis system was used during this testing to obtain measures of body segmental motion.

During inflight data collection, the BPAS vest assembly was used to collect EMG and acceleration data during a series of arm raises. Inflight testing involved four test conditions: 1) 15 arm raises while free-floating, 2) 15 arm raises while free-floating with the addition of foot pressure, 3) 15 arm raises while attached to the Mir support surface, 4) 15 arm raises while bunged to the Mir treadmill. The foot pressure boots were worn during test conditions 2 and 3. No force plate or motion analysis data was obtained in flight.

RESULTS

Inflight - The addition of foot pressure results in increased muscle co-contraction relative to movement conditions without the pressure boots. This measure is a further reflection of the increase in muscle activation caused by the addition of foot pressure. Free-floating arm movements performed without foot pressure resulted in the elimination or severe reduction of the lower limb muscle activation always observed prior to arm movements made while upright in unit gravity.

Free-floating arm movements performed with the addition of foot pressure (provided by the pressure boots) resulted in the lower limb muscle activation always observed prior to arm movements made while upright in unit gravity.

Ground-based - The crewmember demonstrated decrements in postural control associated with voluntary arm movements. The subject increased the magnitude of COP motion decreases in arm acceleration features. This increased COP motion brings the subject closer to the limits of the base of support, thus jeopardizing postural stability. Thus, the subject unable to optimally perform the arm raise task and demonstrated less postural control during the arm motion after space flight. The data indicates that the precise neuromuscular activation patterns necessary for optimal arm movement were not produced after space flight.

CONCLUSIONS

Evidence suggests that there are a wide range of individual responses of the movement control system to space flight and the ground-based Posa test can be utilized to characterize this response range. The ability to generate the same neuromuscular activation patterns that are used to perform the preflight movement is compromised after space flight. No preliminary conclusions concerning the inflight data can be drawn at this time. However, evidence from previous flights has consistently indicated that the addition of foot pressure results in enhanced neuromuscular activation.

PUBLICATIONS

1. Layne, C.S., Bloomberg, J.J., McDonald, P.V., Mulavara, A.P., and Pruett, C.J. The use of foot pressure to enhance neuromuscular activation during space flight. Annual Meeting of the American Institute of Aeronautics and Astronautics, Houston, TX, March, 1996.

2. Layne, C.S., McDonald, P.V., Mulavara, A.P., Kozlovskaya, I.B., and Bloomberg, J.J. Adapting neuromuscular synergies in microgravity. Bernstein's Traditions in Motor Control Conference, Pennsylvania State University, University Park, PA, August, 1996.

3. Layne, C.S., McDonald, P.V., Pruett, C.J., Mulavara, A., Kozlovskaya, I.B., Voronov, A.V., and Bloomberg, J.J. The impact of space flight on anticipatory muscle activation. Annual Meeting of the American Institute of Aeronautics and Astronautics, Houston, TX, March, 1996.

4. Layne, C.S., Mulavara, A.P., McDonald, P.V., Pruett, C.J., and Bloomberg, J.J. Somatosensory input enhances neuromuscular activation during movements performed while free-floating in microgravity. Society for Neuroscience Annual Meeting, Washington, D.C. November, 1996.

5. Mulavara, A.P., McDonald, P.V., Layne, C.S., Poliner, J., Pruett, C.J., and Bloomberg, J.J. Quantifying adaptive preparatory postural adjustments that occur following space flight. 14th Annual Houston Conference on Biomedical Engineering Research, Houston, TX, February, 1996.

6. Layne, C.S., Spooner, B.S. Microgravity effects on "postural" muscle activity patterns. Adv. in Space Res. 1994 (in press).

7. Layne, C.S., McDonald, P.V., Mulavara, A.P., and Bloomberg, J.J. "Adaptations in movement control after space flight.." Annual Meeting of the North American Society for Psychology of Sport and Physical Activity, St. Charles, IL, June, 1998.

8. Layne, C.S., Mulavara, A.P., McDonald, P.V., Pruett, C.J., Kozlovskaya, I.B., and Bloomberg, J.J. "The impact of long-duration space flight on upright postural stability during unilateral arm raises." Annual Meeting of the Society for Neuroscience, New Orleans, LA, October, 1997.

9. Layne, C.S., Mulavara, A.P., Pruett, C.J., McDonald, P.V., Kozlovskaya, I.B., and Bloomberg, J.J. "The use of inflight foot pressure as a countermeasure to neuromuscular degradation." Acta Astronautica, vol. 42, no. 1-8, 231-246 (1998).

Investigation Title: Assessment of Humoral Immune Function During Long-Duration Space Flight

Principal Investigator(s): Clarence F. Sams, Ph.D., NASA/Johnson Space Center; A.T. Lesnyak, Institute of Biomedical Problems

Additional Investigators: Irina Rykova, Richard Meehan, and Patricia Giclas

INVESTIGATION OBJECTIVES

1. Determine the effects of long-duration space flight on baseline levels of immunoglobulins in serum and assess the ability to produce appropriate antibodies in response to a specific antigenic challenge.
2. Assess secretory immune function by measuring salivary IgA and lysozyme levels.
3. Evaluate the responsiveness of B-cells to polyclonal activators immediately after space flight.

PHASE 1 MISSIONS

NASA 2 - NASA 4, NASA 6, NASA 7

OPERATIONAL ACTIVITIES

An inflight vaccination with specific antigens were used test the ability to mount an antibody response in vivo. Blood and saliva was collected from the test subjects before flight, before immunization during flight, 7 days, 11 days, 14 days, 17 days, 21 days, and 28 days after the immunization.

RESULTS

Status of Data Received/Analyzed: All samples have been collected. Initial measurements of the pre-immunization antibody titers for the preflight and inflight samples has been performed for the 4 common pneumococcal isotypes for the subjects from each mission. The remaining sample analysis is being performed in batch with the other NASA-Mir subjects and their age/sex matched ground control group.

CONCLUSIONS

No conclusions

PUBLICATIONS

No publications

Investigation Title: Bone Mineral Loss and Recovery after Shuttle-Mir Flights

Principal Investigator(s): Linda C. Shackelford, M.D., NASA/Johnson Space Center; Viktor Oganov, M.D., Ph.D.

Additional Investigators: Adrian LeBlanc, Ph.D., Helen Lane, Ph.D., Scott M. Smith, Ph.D., Steve Siconolfi, Ph.D., Boris Morukov, M.D., and Inessa B. Koslovskaya, M.D.

INVESTIGATION OBJECTIVES

1. Determine the regional losses in bone mineral density and lean body mass of the crewmembers of each of the Phase 1 Shuttle-Mir flights.
2. Determine the regional rate and extent of recovery of the bone mineral and lean tissue in the above crewmembers.
3. Determine the muscle strength of the lower extremities and back before and after flight. Relate muscle strength data to the bone loss during flight and to the degree and rate of bone recovery postflight.
4. Determine the levels of serum and urinary markers of bone metabolism before and after flight.

PHASE 1 MISSIONS

Mir 21/NASA 2, Mir 22/NASA 3, Mir 23/NASA 4, Mir 24/NASA 5, Mir 25/NASA 6, Mir 26/NASA 7

OPERATIONAL ACTIVITIES

Dual energy x-ray absorptiometry (DEXA) scans were obtained pre- and postflight using a Hologic QDR 2000 whole densitometer (U.S.) or QDR 1000W densitometer (Russia). Bone mineral density data were obtained from scans of the whole body, lumbar spine, proximal femur (hip) and calcaneous (heel). Whole body and regional measurements of lean tissue mass (LTM) were obtained from the whole body scans. Testing time points were: L-60 (60 days prior to launch), L-30, R+5 (5 days after landing), R+180, R+360, R+720 and R+1080 days.

Strength testing was performed pre- and postflight using a LIDO isokinetic dynamometer. Peak torque was measured for muscle groups in the legs and back. Testing time points were the same as for DEXA scans.

Serum and urinary markers of bone metabolism were measured pre- and postflight. Urine is collected over a 24-hour period; serum was collected by a fasting blood draw. Urine markers include total calcium, pyridium cross-links, n-telopeptide, hydroxyproline and creatinine. Serum markers included total and ionized calcium, pH, calcitonin, parathyroid hormone (PTH), osteocalcin, total and bone-specific alkaline phosphatase and vitamin D. Testing time points were: L-30, L-7, R+0 (landing day), R+7, R+14 and R+180 days.

Calcium kinetics testing was conducted pre-, in- and postflight during the NASA 6 and NASA 7 missions. The 22-day protocol included collection of urine, blood, saliva and fecal samples (fecal samples were not collected in flight, however) and the administration of stable calcium isotopes at the beginning of the 22-day test protocol. Testing time points (start of the 22-day protocol) are L-45 days, FD 28 (flight day 28), FD 96, R+3 days, R+6 months, and R+12 months. Samples will be analyzed to determine the levels of the stable isotopes administered for this protocol (^{44}Ca and ^{42}Ca).

RESULTS

All pre- and postflight U.S. DEXA data for the NASA 2 - NASA 7 missions have been analyzed. Russian cosmonaut DEXA data will be analyzed when all of the scan files have been received. Strength testing data analysis is approximately 50% complete. Serum and urinary markers of bone metabolism sample and data analysis is approximately 75% complete. Calcium kinetics sample analysis is complete for the NASA 6 samples collected and approximately 15% complete on the NASA 7 samples collected thus far. Completeness of data collected on the cosmonauts can not be verified at this time.

Preliminary DEXA findings on the crewmembers whose data have been analyzed to date indicate that the regional bone changes are similar to those documented in the 18 cosmonauts studied previously, both in terms of the variability in bone loss among individuals, as well as the site-specific variability in bone loss within a given individual. One NASA crewmember has shown complete bone density recovery at 6 months. All other NASA crewmembers still show significant losses with incomplete recovery. Muscle strength results will be correlated with bone density results during the 3-year recovery period and reported at a later date. Preliminary bone marker findings are not available at this time.

CONCLUSIONS

There are no conclusions to be drawn at the present time.

PUBLICATIONS

1. Shackelford, L., Feiveson, A., Spector, E., LeBlanc, A., and Oganov, V. "Prediction of femoral neck bone mineral density change in space." 12th Man in Space Symposium, Washington, DC (June, 1997).

Investigation Title: Cardiovascular Investigations - Adaptive Changes in Cardiovascular Control at µG (E712)

Principal Investigator: C. Gunnar Blomqvist, M.D., Ph.D., University of Texas Southwestern Medical Center

Additional Investigators: Benjamin D. Levine, M.D., Boyce Moon BSBE, James A. Pawelczyk, Ph.D., Julie Zuckerman R.N., Cole A. Giller, Ph.D., M.D., and Lynda Denton Lane, M.S., R.N.

INVESTIGATION OBJECTIVES

Adaptation to microgravity causes changes in the autonomic nervous system that have significant effects on the control of blood flow and blood pressure. These changes result in orthostatic intolerance, i.e. inability to provide sufficient blood flow to body tissues, particularly to the brain, in the upright body position upon return to Earth.

Our overall objective was to provide new physiological data that will improve our understanding of the function of the human heart and blood vessels in space and on return to Earth.

We conducted the current experiment as an integrated cardiovascular experiment based on sessions performed jointly with Dwain L. Eckberg, MD. and William Cooke, Ph.D. of the McGuire Research Institute, University of Virginia, Richmond, Virginia as well as Friedhelm Baisch, M.D., DLR, Cologne, Germany. Autonomic Mechanisms During Prolonged Weightlessness (E-709)

The primary hypothesis to be tested was that adaptation to the unique environment of microgravity causes alterations in the autonomic nervous system that interact with microgravity induced changes in body fluid distribution, and result in orthostatic intolerance upon return to Earth. We further hypothesized that this adaptation occurs rapidly and completely within the first few days-weeks of space flight and does not progress with long-term (months) exposure. We attempted to achieve the following specific objectives:

1. Establish whether efferent sympathetic nerve activity increase appropriately in response to baroreflex and non-baroreflex mediated stimuli before and after space flight. Our hypothesis was that adaptation to microgravity results in blunted reflex responsiveness with a relative decrease in efferent sympathetic nerve activity leading to inadequate vasoconstriction and orthostatic hypotension. This hypothesis could not be tested on Mir but data are now available from the studies we performed as members of the Neurolab Autonomic team. *

2. Detect functional abnormalities of the autonomic nervous system pre and postflight, and furthermore define the effects and time course of adaptation during space flight by applying integrated, clinical tests of autonomic function. Simple to perform, non-invasive tests such as the quantitative Valsalva maneuver, estimates of heart rate and blood pressure variability, cold pressor test, and static handgrip exercise can provide insights into the adequacy of afferent input, central processing of afferent signals, and sufficiency of neural and vasomotor responsiveness. Indirect, non-invasive measures of autonomic balance, including linear and non-linear variability of heart rate, blood pressure, and cerebral blood flow were obtained before, during and after flight. **

3. Determine if regulation of the cerebral circulation change in parallel with or independently of regulation of the systemic circulation before, during or after adaptation to microgravity. By measuring changes in cerebral blood flow velocity non-invasively using transcranial Doppler, we estimated changes in cerebral blood flow and resistance and related these to changes in systemic flow and resistance in response to metabolic (hypo- and hyperventilation) and hemodynamic (head-up tilt) provocative maneuvers. We hypothesized that in some individuals, autoregulatory failure may occur independent of systemic circulatory failure after space flight.

* We originally planned to measure carotid baroreflex responses; however, technical problems with the equipment required that we delete the measurement.

** Direct measurements of sympathetic nerve activity and norepinephrine Spillover were proposed; however, the crew declined participation.

PHASE 1 MISSIONS

Mir 23/Dara Mir 97E, Mir 24/NASA 6, Mir 25/NASA 7

OPERATIONAL ACTIVITIES

Operational activities involved baseline data collection setup, baseline data collection, crew training and familiarization, and procedure verification.

Our participation in the Mir 23/Dara Mir 97E Cardio experiments (which were closely coordinated with our present NASA7/Mir 25 experiments) required that we travel to DLR in Cologne Germany From August 18 - 27, 1996 for baseline data collection setup and again on September 21 - October 3, 1996 to conduct baseline data collection # 5. Mir 23/Dara Mir 97E later required our travel to Star City, Russia from November 8 - 20, 1996 for baseline data collection setup and again from November 30 - December 7, 1996 for baseline data collection # 6. From January 27 - February 4, 1997 we returned to Star City, Russia to conduct baseline data collection # 7. Our Mir 23 operational activities concluded with a trip to Star City, Russia to conduct baseline data collection # 8 during August 14 - 22, 1997.

NASA 6/Mir 24 experiments 712/709 required procedure verification; therefore, we traveled to Star City, Russia from March 14 - 22, 1997, to prepare. We traveled again to Star City from May 5 - 9, 1997 to setup for baseline data collection. Crew familiarization and training was achieved during our next trip to Star City from May 15 - 17, 1997. While still in Star City we conducted baseline data collection and crew training from May 18 - 22, 1997. On June 3, 1997 we traveled to NASA JSC, Houston, TX for preliminary examination of baseline data collection hardware and facilities. Crew training brought us back to Star City, Russia from June 6 - 22, 1997. From August 26 - 29, 1997 we traveled to NASA JSC, Houston, TX to setup for baseline data collection for both NASA 6/Mir 24 and NASA 7/Mir 25. We returned to NASA JSC from September 1 - 4, 1997 for additional setup and integrated team practice for NASA 6 preflight baseline data collection.

NASA 7/Mir 25 crew training and preflight baseline data collection required travel to NASA JSC from September 15 - 26, 1997. We concluded our NASA 7/Mir 25 activities with a return to Star City, Russia from August 20 - September 12, 1997 to conduct postflight data collection on the Mir 25 crew.

RESULTS

We are currently verifying collected data and writing supplemental software to complete the analysis of those data. The data analysis is performed jointly with Dr. Eckberg et al. of the University of Virginia.

CONCLUSIONS

Pending

PUBLICATIONS

Pending

Investigation Title: Cardiovascular Investigations - Autonomic Mechanisms During Prolonged Weightlessness (E709)

Principal Investigator: Dwain L. Eckberg, M.D., McGuire Research Institute

Additional investigators: William H. Cooke, Ph.D., Friedhelm J. Baisch, M.D., James F. Cox, Ph.D., and Kari U.O. Tahvanainen, M.S.

INVESTIGATION OBJECTIVES

1. To explore the probability that the disordered arterial baroreflex malfunction documented during weightlessness is part of, and a contributor to a broad range of autonomic abnormalities, and to understand the mechanisms and implications of such abnormalities during, and after long-duration space flights.

PHASE 1 MISSIONS

Mir 23, Mir 25

OPERATIONAL ACTIVITIES

We successfully recorded EKG, beat-to-beat arterial pressure, cerebral blood flow velocity, and whole-body fluid distribution during a battery of tests that activate different afferent fibers, evoking different patterns of neural and cardiovascular responses. Data were recorded L-14, MD18, and R+1 and 15 during Mir 23 for one cosmonaut. Data were recorded L-14, MD114, 148, 182, and R+1 and 15 for one, and L-12, MD120, 183, and R+15 for another cosmonaut during Mir 25.

RESULTS

Despite recording data on such a small sample of cosmonauts, our data suggest that prolonged weightlessness: 1) decreases vagal cardiac control; 2) decreases the buffering of arterial pressure by RR-interval variability at respiratory frequencies; 3) decreases arterial baroreflex gain despite indirect evidence of increased sympathetic traffic (this was assessed during Valsalva’s maneuver, by spontaneous systolic pressure-to-RR-interval slopes, and by cross-spectral analysis of RR-interval and systolic pressure spectral power. Analysis of data is not complete.

CONCLUSIONS

Prolonged exposure to microgravity attenuates baroreflex regulation of arterial pressure, and alters neural cardiac control. Continuing in-depth analysis may reveal other, more telling results which may have clinical implications.

PUBLICATIONS

Manuscripts are in preparation, and are targeted for publication in Journal of Applied Physiology

Investigation Title: Collecting Mir Source and Reclaimed Water for Postflight Analysis

Principal Investigator(s): Richard L. Sauer, P.E., NASA/Johnson Space Center; Yuri Sinyak, Ph.D., Institute of Biomedical Problems

Additional Investigators: Lizanna Pierre, John Schultz, Ph.D., Leonid Bobe, Ph.D., Nikoli Protasov, Ph.D., and V. M. Skuratov, Ph.D.

INVESTIGATION OBJECTIVES

1. Characterize the chemical composition of Mir recycled water, Russian ground supplied water prior to launch and on orbit, and the Mir humidity condensate to support development and testing of the water recycling and monitoring systems for the ISS.

2. Determine and compare the chemical composition of Mir and Shuttle condensate.

3. Determine whether the potable water on board Mir meets the Joint U.S./Russian water quality specifications for ISS.

PHASE 1 MISSIONS

This experiment has flown under the Human Life Sciences Discipline during the Mir 18/NASA 1, Mir 19, Mir 20/STS-74, and Mir 21/NASA 2/STS-79 missions. In addition, this activity was performed under the Space Medicine Program during the Mir 22/NASA 3/STS-81, Mir 23/NASA 4/STS-84, Mir 23/NASA5/STS-86, Mir 24/NASA6/STS-89 and the Mir 25/NASA7/STS-91 missions.

OPERATIONAL ACTIVITIES

Recycled and stored water samples were collected periodically during each mission using U.S. developed water sampling hardware. In addition, raw unprocessed humidity condensate was collected using Russian supplied hardware, while partially processed condensate was collected using U.S. supplied hardware. The partially processed condensate samples were collected as a result of ethylene glycol leaks on board the Mir, to assess the ability of the water processor system to remove this contaminant.

RESULTS

In general, the recycled and stored water supplied to the Mir Space Station met NASA, Russian Space Agency (RSA), and/or U.S. Environmental Protection Agency (EPA) standards. Exceptions were found to include total organic carbon (TOC) and turbidity in the recycled water which routinely exceeded NASA standards. The TOC in some cases, exceeded Russian standards as well. Other parameters such as ethylene glycol, barium, nickel, chloroform, phenol, and dioctyl phthatate occasionally exceeded NASA, RSA or EPA standards. All but the TOC violations were transient.

The humidity condensate exhibited steadily increasing levels of ethylene glycol throughout Phase 1. This is believed to reflect the increased levels of ethylene glycol in the Mir atmosphere following coolant loop leaks and maintenance activities. In one case, the presence of ethylene glycol in a condensate sample alerted the ground and crew to the presence of a previously undetected coolant loop leak.

CONCLUSIONS

The chemical quality of the recycled and stored water, as determined through postflight analysis met performance and potability requirements. The analysis of samples has provided important data for assessing the potability of recycled water. In addition, these data will be instrumental in developing appropriate water quality monitoring standards for ISS.

PUBLICATIONS

1 .Pierre, L.M., Schultz, J.R., Johnson, S.M., Sauer, R.L., Sinyak, Y.E., Skuratov, V.M., and Protasov, N.N., Collection and Chemical Analysis of Reclaimed Water and Condensate from the Mir Space Station, SAE #961569, 26th International Conference on Environmental Systems, Monterey, California July 1996.

2. Pierre, L.M., Schultz, J.R., Sauer, R.L. Sinyak, Y.E., Skuratov, V.M., and Protasov, N.N., Chemical Analysis of Potable Water and Humidity Condensate Collected During the Mir 21 Mission, SAE #97ES-224, 27th International Conference on Environmental Systems, Lake Tahoe, Nevada July 1997

3. Sauer, R.L., Sinyak, Y.E, Pierson, D.L, Schultz, J.R., Straub, J.E., Pierre, L.M., Limardo, J.M., Koenig, D.W., Assessment of the Potable Water Supply on the Russian Mir Space Station, American Institute of Aeronautics and Astronautics Life Sciences and Space Medicine Conference, Houston, TX March 1996

Investigation Title: Crewmember and Crew-Ground Interactions During NASA-Mir

Principal Investigator: Nick A. Kanas, M.D., VA Medical Center at San Francisco

Additional Investigators: Vyacheslav Salnitskiy, Ph.D., Vadim Gushin, M.D., Olga Kozerenko, M.D., Charles R. Marmar, M.D., Alexander Sled, M.S., and Daniel S. Weiss, Ph.D.

INVESTIGATION OBJECTIVES

1. To measure and characterize crewmember and mission control personnel tension, cohesion, and leadership role during five Shuttle-Mir missions

PHASE 1 MISSIONS

NASA 3 - NASA 7

OPERATIONAL ACTIVITIES

None.

RESULTS

The data collection phase of this study ended in August 1998, although not all data have been received as of January 25, 1999. Five U.S. and four Russian space crews and their ground support personnel were studied during Shuttle-Mir missions that took place from 1995 to 1998. The number of subjects who participated included 6 astronauts, 11 cosmonauts, and 41 U.S. and 18 Russian mission control personnel. The overall compliance rate was 80%. To test hypotheses related to psychosocial issues affecting the 1st half versus the 2nd half of a typical mission, all of the subject responses were arrayed in terms of the midpoint of each subject's mission for each subscale of the Profile of Mood States (POMS), Group Environment Scale (GES), and Work Environment Scale (WES). Preliminary analyses of the GES data received to date showed that crewmembers reported significant declines in the 2nd half of the missions on measures of cohesion, leader support, and task orientation. Crew self-discovery dropped throughout the missions. There were significant overall differences between the Mir crews and personnel in mission control on five of the six POMS subscales, with astronauts and cosmonauts reporting less anxiety and dysphoria than mission control personnel. However, both subject groups obtained significantly lower scores than published adult norms on these measures. On the WES, Mir crewmembers scored significantly higher than did mission control personnel on measures of perceived managerial control and comfort with their physical environment. Managerial control scores for the crewmembers were significantly higher than published normative scores for ground-based work groups. Ground subjects scored significantly lower than the norms for physical comfort, indicating that they were less satisfied with their physical environment than other work groups. Evidence supporting the occurrence of displacement of tension and dysphoria to people outside the group was found among both crew and mission control subjects, with all measures of tension and dysphoria correlating in the predicted negative direction with supervisor support. There also was a positive relationship between leader support and cohesion for both crew and mission control subjects. U.S. and Russian subjects showed some variation in response, and these cultural differences will be analyzed in the future.

CONCLUSIONS

Preliminary analyses of the data received to date using a biphasic analysis supported 4 of the 6 study hypotheses regarding the effects of the phase of a space mission on tension, cohesion, and leadership role. As predicted, crew cohesion and perceived leader support declined significantly in the 2nd half of the missions, possibly indicating asthenic changes and disruptions in interpersonal relationships. The significant crew-ground differences in measures of dysphoria might be more reflective of the significantly low POMS scores reported from space than of a problem on the ground. The evidence for displacement suggests that it is important for crewmembers to learn strategies of openly dealing with on-board tension and dysphoria rather than displacing these negative affects to mission control personnel. The same can be said for the mission control group in relationship to displacing negative affects to agency management. In both subject groups, perceived leader support correlated with cohesion, illustrating the importance of the supportive role of the leader on the group’s ability to work together. The findings from this study suggest a number of important countermeasures that can be developed for use in future manned space missions in the areas of preflight selection and training; inflight support; and postflight readaptation to the social environment on Earth.

PUBLICATIONS

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2. Kanas, N, Salnitskiy, V, Grund, E, Gushin, V, Kozerenko, O, Sled, A, Weiss, DS, and Marmar, CR: Interactions of crewmembers and mission control personnel during Shuttle-Mir missions: Preliminary findings. Proceedings from the First Biennial Space Biomedical Investigators' Workshop of the Universities Space Research Association. NASA/JSC, January 11-13, 1999.

Investigation Title: The Effects of Long-Duration Space Flight on Eye, Head, and Trunk Coordination During Locomotion

Principal Investigator: Jacob J. Bloomberg, Ph.D., NASA/Johnson Space Center

INVESTIGATION OBJECTIVES

Determine if extended duration space flight modifies head-trunk coordination strategies that occur during terrestrial locomotion and determine if these changes are associated with disturbances in lower limb kinematics and muscle activity patterns of the leg during locomotion.

PHASE 1 MISSIONS

Mir 18, Mir 19, Mir 21, Mir 22, NASA 1, NASA 3, NASA 4

OPERATIONAL ACTIVITIES

Subjects were tested before and after 3-6 months aboard the Mir Space Station. Subjects performed two protocols: 1) walking on a motorized treadmill while performing different gaze fixation tasks; 2) overground locomotion on a 6.0 m walkway. Segmental kinematic data were collected with a video-based motion analysis system while muscle activity from the legs was measured using electromyographic methods.

RESULTS

Analysis of roll, pitch and yaw head and trunk movements during walking revealed postflight alterations in head and trunk movement control in all three planes of motion. Change in lower limb coordination was exemplified by modification in control of thigh, knee and ankle angular displacement, particularly during the heel-strike event of the gait cycle. Subjects also experienced decreased dynamic visual acuity during postflight walking.

CONCLUSIONS

Taken together these data indicate that exposure to long-duration space flight causes alteration in head and trunk movement control, lower limb coordination and dynamic visual acuity during locomotion. Thus, after long-duration space flight there is a loss of integration of the multiple full-body cascade of sensorimotor events required for efficient terrestrial locomotion.

PUBLICATIONS

Articles

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3. Reschke M.F., Bloomberg, J.J., Harm D.L., Paloski W.H., Layne, C.S., McDonald P.V. Posture, locomotion, spatial orientation, and motion sickness as a function of space flight. Brain Research Reviews, 28: 102-117, 1998.

Abstracts

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7. LaFortune, M.A., McDonald, P.V., Layne, C.S., Bloomberg, J.J. Space flight modifications of the human body shock wave transmission properties. Presented at the Annual Meeting of the Canadian Society for Biomechanics, Vancouver, B.C., Canada, August, 1996.
8. McDonald, P.V., Lafortune, M.A., Layne, C.S., Bloomberg, J.J. Challenges to head stability after space flight. Presented at the Society for Neuroscience Annual Meeting, November, 1996.
9. Peters, B.T., Bloomberg, J.J., Layne, C.S., McDonald, P.V., Huebner, W.P. Eye, head, and trunk phase relationships during treadmill locomotion while viewing visual targets at different distances. Presented at the Society for Neuroscience Annual Meeting, November, 1996.
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23. Mulavara, A.P., Verstraete, M.C., McDonald, P.V., Layne, C.S., Bloomberg, J.J. Coordination between the head and trunk during locomotion after long-duration exposure to weightlessness. Annual Houston Conference on Biomedical Engineering Research. February, 1999.

24. Blooomberg, J.J., Mulavara, A.P., McDonald, P.V., Layne, C.S., Merkle, L.A., Kozlovskaya, I.B. Head and trunk movement control during locomotion after long-duration space flight. Vestibular Influences on Spatial Orientation. A satellite following the ninth Annual Meeting of the Society for the Neural Control of Movement, April 16-19, 1999, Princeville, HI.

Investigation Title: The Effects of Long-Duration Space Flight on Gaze and Voluntary Head Movements

Principal Investigator(s): Millard F. Reschke, Ph.D., NASA/Johnson Space Center; Inessa B. Kozlovskaya, M.D., Ph.D., D.Sc.

Additional Investigators: Jacob J. Bloomberg, Ph.D., Deborah L. Harm, Ph.D., William P. Huebner, Ph.D., Ludmilla Kornilova, M.D., and William H. Paloski, Ph.D.

INVESTIGATION OBJECTIVES

The primary objective of this study was to investigate the emergence or alteration of goal-oriented strategies required to maintain effective gaze when the interactive sensorimotor systems required for this function were modified following extended exposure to the stimulus rearrangement of space flight.

PHASE 1 MISSIONS

STS-60, STS-63, Mir 18, STS-71, Mir 19, Mir 21, NASA 2

OPERATIONAL ACTIVITIES

The design of the proposed experiment protocol was negotiated by the U.S. and Russian investigators through a series of meetings beginning in 1992 with meetings in both Moscow and Houston (Johnson Space Center). This effort was endorsed by NASA and Russian Life Sciences management as a joint effort to combine U.S. and Russian experimental procedures. In the experiment the subjects were asked to perform five major tasks. (1) Target Acquisition: The target acquisition task included acquiring targets in both the horizontal and vertical planes at preset angular distances, including targets that are beyond the EOM range. Two tests of target acquisition were performed. The first test used predictable targets (i.e., the targets are visible at all times, and acquired in a predetermined sequence known to and practiced by the subject). The second test required acquisition of unpredictable targets (i.e., fixation on a central target and a shift of gaze to a newly illuminated target in an unpredictable plane and to an unknown displacement). (2) Pursuit Tracking: Pursuit tracking, in both the horizontal and vertical planes, included pursuit of both predictable sinusoidal targets at frequencies where vision is expected to be dominate, and at higher frequencies that required visual-vestibular contributions for stable gaze. Unpredictable pursuit tracking used position ramps that vary in both maximal displacement and velocity. Pursuit was first done with the eyes only, head held stationary, then with both the head and eyes. (3) Sinusoidal Head Oscillations (head shakes): Voluntary head motions was done in both the horizontal and vertical planes at 0.2, 0.8, and 2.0 Hz with vision (maintaining a fixation point in the primary frontal plane) and with vision occluded (imagine the fix-ation point available with vision). (4) Memorized Head Rotations: Subjects used a head-fixed laser to quickly and accurately align the head with targets successively illuminated in a pseudorandom pattern. Vision was then occluded and the subject attempted to recreate a head rotation pattern matching the stimulus pattern with and without a delay between stimulus presentation and pattern matching. Head rotations were performed in both the horizontal and vertical planes. and (5) Test For Both Spontaneous and Gaze Nystagmus: Modified standard clinical test for both spontaneous and gaze nystagmus were conducted as part of an eye calibration sequence.

Tests for spontaneous nystagmus were done with the eyes open and shut, and gaze nystagmus was tested by having the subjects deviate the eyes to their maximum position in all planes, hold for 20 seconds, and then return to the center primary position. Pre-postflight eye movements were recorded with video and EOG. Head movements were recorded with a triaxial rate sensor assembly mounted on a head cap. The head cap also included a projection laser for calibration of the head.

RESULTS

Findings to date (not final) strongly suggest that the effects seen on short-duration missions (delayed target acquisition, reduced head velocity following flight, high gain in the visual vestibulo-ocular system, failure to suppress the VOR during head/eye target pursuit, etc.) are present following long-duration missions. Most importantly, the effects of long-duration flights relative to the short-duration Shuttle missions, is the duration of the modification in response parameters. That is, the long-duration flights produce long lasting effects. Recovery, particularly in the pursuit system was not observed in all crewmembers even 64 days following flight.

CONCLUSIONS

Final conclusions will follow with the completion of data analysis.

PUBLICATIONS

1. Reschke M.F., Bloomberg, J.J., Harm D.L., Paloski W.H., Layne, C.S., and McDonald P.V. Posture, locomotion, spatial orientation, and motion sickness as a function of space flight. Brain Research Reviews, 28(1-2): 102-117, 1998.

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Investigation Title: Evaluation of Skeletal Muscle Performance and Characteristics

Principal Investigator(s): Steven F. Siconolfi, Ph.D., Wayne State University; and Inessa B. Kozlovskaya, M.D.

Additional Investigators: Charles S. Layne, Ph.D., Yuri A. Koryak, Ph.D., Daniel L. Feeback, Ph.D., and Viktor J. Stepantsov, Ph.D.

INVESTIGATION OBJECTIVES

1. To evaluate how skeletal muscle performance and characteristics adapt to microgravity during long-duration space flight.
2. To determine the initial time course for readaptation to 1-g.
3. To evaluate the efficacy of the Russian Countermeasures.

PHASE 1 MISSIONS

Mir 22/NASA 3

OPERATIONAL ACTIVITIES

Preflight and postflight (1) muscle strength, endurance and tone, (2) neuromuscular efficiency, (3) voluntary and evoked contractions, and (4) preflight, inflight, and postflight graded cycle exercise.

RESULTS

Status of Data Analysis

Metabolic Gas Analysis System (MGAS) and muscle strength data is complete. EMG data analysis is 25% complete. Due to decreased funding, EMG analysis will be delayed.

Preliminary Research Findings

Initial muscle strengths were near preflight values and either improved or were maintained for all muscle groups except for knee extensors and flexors for two subjects. The other subject showed initial decreases but returned toward preflight values by the 3rd week of recovery.

CONCLUSIONS

1. Russian countermeasures were generally effective for maintaining gross muscle function.
2. Integrated muscle function was slightly compromised.
3. Russian countermeasure program provides excellent starting point to refine neuromuscular countermeasures for space flight.

PUBLICATIONS

Not provided by PI.

Investigation Title: Frames of Reference for Sensorimotor Transformations

Principal Investigator: Alain Berthoz, Ph.D., LPPA/CNRS-Collëge de France

Additional Investigators: Dr. Joseph McIntyre, Dr. Mark Lipshits, and Dr. Victor Gurfinkel

INVESTIGATION OBJECTIVES

1. To test the hypothesis that gravity can aide in coordinating visual and haptic sensory information and to measure how human subjects adapt eye-hand coordination to weightlessness.

PHASE 1 MISSIONS

NASA 4, NASA 5 (NASA 5 cancelled in flight due to failure of equipment)

OPERATIONAL ACTIVITIES

The NASA astronaut performed a battery of psychophysical tests in which he was required to coordinate visual and haptic (touch and movement) sensory information, using the French Cognilab workstation and Robotop force-actuated joystick.

RESULTS

On the ground, subjects demonstrate the so-called "oblique effect" for the sensation of visual and haptic information, identifying more quickly and precisely vertically and horizontally oriented stimuli. This effect is altered when the subject is tilted with respect to gravity, but remains when measured in the 0G environment.

CONCLUSIONS

These results indicate that the human nervous system uses both proprioceptive and graviceptive information for encoding stimulus orientations, but can substitute a purely proprioceptive reference frame when gravity is absent.

PUBLICATIONS

1. Lipshits, M. and McIntyre, J. (1999) Gravity affects the preferred vertical and horizontal in visual perception of orientation. NeuroReport, in press.

Investigation Title: Gas Analyzer System for Metabolic Analysis Physiology (GASMAP) Facility Operations

Principal Investigator(s): Floyd B. Booker, NASA/Johnson Space Center

Additional Investigators: N/A

INVESTIGATION OBJECTIVES

1. Record a subjects gas exchange with inspiration and expiration readings during exercise.
2. Analyze gas exchange.
3. Measure cardiovascular and cardiopulmonary parameters.
4. To assure the greatest possible analyzer accuracy and response time.

PHASE 1 MISSIONS

NASA 2 - NASA 5

OPERATIONAL ACTIVITIES

The Gas Analyzer System for Metabolic Analysis Physiology (GASMAP) is an instrument that analyzes the inspired and expired breath of subjects and performs metabolic calculations to aid in the health assessment of astronauts in microgravity. GASMAP can be used in conjunction with a bicycle ergometer, treadmill, EKG, blood pressure monitor, and rebreathing apparatus. GASMAP was delivered to the Mir Space Station during the NASA 2 mission. The GASMAP was powered up every 90 days for calibration purposes. The values measured by the GASMAP from calibration gases were recorded and downlinked for comparison with actual values of gases in the calibration tanks. Hardware checks were performed periodically during the NASA 3 mission to verify the operational status of the GASMAP unit. Two types of hardware checkouts were performed: partial checkouts and full checkouts. Partial checkouts were performed approximately every 30 days while full checkouts were performed every 90 days. The operational status of the GASMAP unit was also verified during the NASA 4 mission using partial and full checkouts. Operational status checks of the GASMAP unit continued on the NASA 5 mission until an accident occurred during the docking of a Russian Progress module. The Spektr module of the Mir Space Station was permanently closed after the accident. Consequently, the crew lost access to the GASMAP unit since it was housed in the Spektr module. Plans for GASMAP to support a cardiovascular experiment during the NASA 6 and NASA 7 missions were subsequently canceled.

RESULTS

The GASMAP was calibrated to measure N2, O2, CO2, Ar, He, C2H2, and C18O during the calibration exercises and checkout procedures. GASMAP did not require calibration to measure calibration gases accurately. The analyzer measurements were within + 1.25% of full scale of analytical values, except for CO2, and He; however, He and CO2 readings were within + 3% of full scale analytical calibration gas values.

CONCLUSIONS

The first generation GASMAP analyzer on board Mir exhibited exceptional stability during the checkout procedures. We think the He and CO2 measurements can be corrected by changing the analyzer warm-up period to include filament run time.

PUBLICATIONS

N/A

Investigation Title: Inflight Radiation Measurements

Principal Investigator: Gautam D. Badhwar, Ph.D., NASA/Johnson Space Center

Additional Investigators: Drs. V. Petrov, Inna Tchernych, and V. Shurshakov

INVESTIGATION OBJECTIVES

1. Measure crew radiation exposures.
2. Compare crew measurements using US and Russian techniques.
3. Map the radiation dose rate in all Mir compartments.
4. Obtain time resolved radiation data using a tissue equivalent proportional counter (TEPC) in various Mir modules to help in understanding the ISS radiation environment and gather data on radiation quality factor.

PHASE 1 MISSIONS

NASA 1 - NASA 7

OPERATIONAL ACTIVITIES

Crew read TEPC data every five days and relayed to the ground. The data were used to determine safe sleeping crew quarters. Data were periodically transfer to the disk and send then to ground on next Shuttle mission. Periodically the data were transferred electronically.

RESULTS

(1) Dose rates vary by about a factor of two each module. Kvant module had the highest rate, (2) TLDs do not measure the total dose rate, (3) In the Core module, the galactic cosmic ray (GCR) and trapped (SAA) dose rates were approximately equal, (4) GCR rates vary by ~ 15% within modules, and are well correlated with the deceleration potential, (5) Trapped dose rates vary considerably from module to module (~ 5) and with changing solar activity and altitude, (6) Trapped dose rate are well described by a power law relationship of atmospheric density computed 400 days prior to the observations, (7) Established the secular drift of the SAA with time to 0.29 degrees W longitude, and slight northerly component, (8) Particles with linear energy transfer (LET) > 10 keV/micron account for ~ 15% of dose but 65% of the dose equivalent, (9) Models of solar particles transmissions through the geomagnetic field are not in good agreement with the observations, and (10) The highest crew exposure rate was measured for the one of the Mir 23/24 crewmembers, with Russians measurements ~ 8% lower than US measurements.

CONCLUSIONS

(1) First direct measurements of SAA drift with help with EVA planning activity for the station, (2) GCR dose rate predicative model, good to ± 15% developed, and (3) The relationship of trapped dose rate with atmospheric density would help to develop time dependent model of SAA, and (4) helped the crew in selecting area of low dose rate and during November 6-7, 1998 solar particle event.

PUBLICATIONS

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3. G.D. Badhwar, V.A. Shurshakov, and Tsetlin, Solar modulation of dose rate on board the *Mir* station, *IEE Trans of Nucl Sci.,* 44, 2529-2541 (1997).
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5. G.D. Badhwar, Radiation Measurements on board the *Mir* orbital station, Phase 1 Symposium, November 1998, Huntsville, Al

Investigation Title: Magnetic Resonance Imaging (MRI) After Exposure to Microgravity

Principal Investigator: Adrian L. LeBlanc, Ph.D., Baylor College of Medicine

Additional Investigators: Inessa Kozlovvskaya, M.D., Ph.D., Valentine Sinitsyn, M.D., Daniel L. Feeback, Ph.D., Harlan Evans, Ph.D., Thomas Hedrick, M.D., Victor Oganov, M.D., Oleg Belichenko, M.D., Ph.D., Linda Shackelford, M.D., and Chen Lin, Ph.D.

INVESTIGATION OBJECTIVES

1. Measure the muscle volumes of the calf, thigh, back and neck using MRI before and after flight. These data will be compared with pre- and postflight muscle performance measurements.

2. Determine and compare the T2 and muscle volume changes on R+0 and R+4 days following space flight using MRI.

3. Determine the change in intervertebral disc size in the lumbar spine after flight and determine the rate of recovery after return to one G.

4. Determine the bone marrow T2 and cellularity of L3 before and after flight using MRI spectroscopy.

5. Document frequency, type, severity, and location of back pain during and after space flight.

PHASE 1 MISSIONS

NASA 1-7. Some data from NASA 6 and 7 still being analyzed.

OPERATIONAL ACTIVITIES

MRI Imaging:

- Muscle volume of the calf
- Muscle volume of the thigh
- Muscle volume of the lower back
- Muscle volume of the neck
- T2 of calf muscle
- lumbar spine disc size and lumbar spine length
- T2 of proton spectroscopy of L3

Fill out back pain questionnaire.

RESULTS

The change in muscle [gastrocnemius, soleus, anterior calf, quadriceps, hamstrings, intrinsic lower back (rotatores, multifidus, semispinalis, spinalis, longissimus, iliocostalis), psoas, neck muscles (splenius capitis, semispinalis capitis, semispinalis cervicus, multifidus)] volume as the percent change from baseline versus the length of flight has been determined in 15 astronauts and cosmonauts. The data include 14 male and one female representing 6 American astronauts and 9 Russian cosmonauts. The flight lengths varied from about 4 months to about 6 months. In spite of the considerable individual variation, it appears that the losses at around 4 months are similar to the 6 month data. This suggests that the amount of volume change has maximized by 4 months of flight. The changes were greatest in the calf and back and somewhat less in the thigh. The inter-individual variation may reflect in part the differences in the inflight exercise protocol followed by crewmembers. There were no measurable changes in the neck muscles measured. Comparison of the flight results with bed rest indicate that the changes in the leg muscles during flight were generally less than bed rest. This is likely a consequence of the exercise countermeasure employed during flight since the bed rest data did not include exercise. The back muscles, however, showed greater loss during flight compared to bed rest, which may be reasonable, considering that the back muscles are active to a substantial degree in bed rest. Postflight each of the flight crew were measured at multiple time points, generally 3-4. These results show that muscle volume recovers at variable rates depending on the region, but generally have returned to baseline by 30-60 days postflight.

Muscle T2 is available on 5 crewmembers, however, the analysis of this data is not complete (does not include NASA 5-7) and therefore conclusions are preliminary. The general pattern is that T2 tends to be increased relative to baseline at the first postflight measurement and almost always elevated at R+14 compared to the initial postflight measurement or baseline. By 30-70 days postflight the T2 has decreased toward baseline in all cases where these measurements were available. Muscle volume changes between R+0 and R+2-4 days after flight are complete on 5 crewmembers (not complete) on which this was available. This data demonstrates muscle swelling can occur during the early reambulation period; this is also usually seen after bed rest. The largest changes are in the calf, particularly the gastrocnemius.

The measurements of disc area and lumbar spine length indicate that there are only minor spine lengthening and disc expansion by the time measurements are obtained on landing day. Measurements are made within 2-4 hours after landing with some walking and sitting up on a stretcher by the crewmember before testing. By 2-4 days postflight there is some slight residual expansion remaining which by 2 weeks is back to baseline. Importantly, we do not see any long-term residual changes in disc size following these flights.

In only 4 individuals were the bone marrow spectroscopic data reasonably complete. In two of the individuals collection of preflight data was not possible and in two others postflight data collection was incomplete because of equipment problems. While the data a re preliminary and incomplete, comparison to the LMS, 17 day mission suggests that although the postflight T2 tens to increase as in the shorter LMS flight, there appears to be some significant differences. For example, three individuals demonstrated significantly reduced values postflight that gradually returned to baseline; this was not seen on LMS. Two other individuals appear to show a similar postflight pattern as LMS.

Out of 15 crewmembers (including one German guest cosmonaut, but not the data from NASA 6 and 7), 7 indicated that they experienced back pain or discomfort during the flight. Generally this occurred in the lower lumbar region during the first week of flight. The pain was typically described as “can be ignored,” lasted a few hours to several days in duration and was most noticeable during or after resting. Some crew indicated that bending or application of massage seem to relieve the pain. Postflight 6 of 15 crewmembers reported significant discomfort for some or all 10 days that monitoring was reported following flight. There were a number of cases where written reports were not available or were not filled out. Whenever possible the crew were asked about their experience during and after flight. When no information was available these were treated as being negative reports and therefore, the incidence rates above may underestimate actual rates.

CONCLUSIONS

There are measurable decreases in muscle volume during flight, which presumably, but not necessarily, represents muscle atrophy. These changes appear to be maximized within the first 4 months of flight. Compared to bed rest without exercise, the inflight muscle changes are less except in the back muscles. Recovery in all muscle groups is complete within 30-60 days after return to Earth, similar to recovery after bed rest. There are muscle volume and T2 changes during the first days and weeks after return from space flight compatible with muscle damage. We did observe small, but no long-term changes in disc size following these flights. There are postflight bone marrow changes with some significant differences compared to the shorter LMS flight. Although about 47% of the crewmembers reported some back pain during flight, the duration and magnitude of this problem seems not to be of major concern for long-duration flight. A more important consideration may be the potential for significant injury/pain after flight since about 40% reported significant postflight discomfort lasting for a number of days to weeks. This may be an important consideration for visits to planets with significant gravity after lengthy flights in microgravity.

PUBLICATIONS

A paper reporting the muscle results is in preparation.

Investigation Title: Microbial Interaction in the Mir Space Station Environment

Principal Investigators: George M. Weinstock, Ph.D., University of Texas Medical School

INVESTIGATION OBJECTIVES

1. Development of a DNA fingerprinting method for microorganisms suitable for space flight.
2. Application to tracking of microbes from NASA-Mir missions to determine the amount of microbial transfer between crew and from the Space Station, (3) Determination of the microorganisms that may transfer most often.

PHASE 1 MISSIONS

Mir18, Mir19, STS-71, Mir22/NASA3

OPERATIONAL ACTIVITIES

DNA fingerprinting technology development and application to microbial samples obtained from the Microbiology Laboratory at JSC.

RESULTS

A rapid and cost effective DNA fingerprinting method was developed for microbial samples. Application of this to isolates of Staphylococcus aureus demonstrated transfer of this bacterium between crewmembers, both during training and during flight. Analysis of a census of other microorganisms that were isolated during these missions showed several other candidates for DNA fingerprint analysis, based on their potential for transfer between crew or from the Space Station to the crew. The DNA fingerprinting method was shown to be applicable to these other types of bacteria.

CONCLUSIONS

Transactions involving microorganisms occur between crew and Space Station environment at a higher frequency that could previously be detected. Tracking of microbes by DNA fingerprinting is a reliable method for detecting and analyzing these movements.

PUBLICATIONS

1. An epidemiological evaluation of Staphylococcus aureus on two Mir missions using rep-PCR. 1997. C. K. Brauning, M.S. Thesis, Univ. Texas Health Science Center, Houston.
2. Comparison of rep-PCR and RFLP analysis by pulsed-field gel electrophoresis for DNA fingerprinting of Staphylococcus aureus. In preparation. C. K. Brauning, D. L. Pierson, G. M. Weinstock.
3. On the mechanism of rep-PCR DNA fingerprinting. In preparation. M. Chidambaram, E. J. Sodergren, D. L. Pierson, and G. M. Weinstock.
4. Transfer of Staphylococcus aureus between humans in a closed environment. In preparation. C. K. Brauning, D. L. Pierson, G. M. Weinstock.

Investigation Title: Microbiological Investigations of the Mir Station and Crew

Principal Investigators: Duane L. Pierson, Ph.D., NASA/Johnson Space Center; Dr. Aleksandr N. Viktorov

Additional Investigators: Theron Groves, Rebekah Bruce, Natalia Novikova, Vladimir Skuratov, and Nadezda Lizko

INVESTIGATION OBJECTIVES

1. Characterize the microbiota of crewmembers, air, surface, and water microbes before, during, and after a long-duration mission aboard the Mir Space Station.
2. Have operationally-ready hardware systems ready for ISS.

PHASE 1 MISSIONS

Mir 18, Mir 19, Mir 22, NASA 3, NASA 4, NASA 5, Mir 24, NASA 6, Mir 25, NASA 7

OPERATIONAL ACTIVITIES

*Crew Microbiology**

Preflight: Launch minus 6, 5, 4, 3, 2, and 1 month(s)

Inflight: Flight Days 15, 35, 55, 85, 115, and 135

Postflight: Return plus 0, 7, and 14 days

Analyses: Throat, nose, ear, hand, scapula, axilla, groin, urine, and feces cultures; Rapid Group A Streptococcus screen; Throat viral culture; Parasitology

*Environmental Microbiology**

Shuttle Air: Middeck, Flight Deck; Sampling at Rollout, launch minus 2 days, Flight Days 2 and 5

Mir Air: 4 sampling locations; Sampling during Shuttle docking and once per month in flight

Shuttle Surfaces: 3 sampling locations; Sampling at Rollout, Launch minus 2 days, Flight Days 2 and 5

Mir Surfaces: 5 sampling locations; Sampling during Shuttle docking and once per month in flight

Shuttle Water: Galley; Sampling at Launch minus 15 and 3 days, Return plus 1 day

Mir Water: 3 sampling locations; Sampling during Shuttle docking and once per month in flight

* Sampling frequency decreased upon implementation of the Space Medicine Program

RESULTS

Developed a surface sampling kit for culturing of microbes on a variety of spacecraft surfaces for inflight analysis.

Conducted microbial air sampling using a Burkard air sampler.

Developed a water microbiology kit for the inflight analysis of spacecraft water.

Conducted the first inflight microbial analysis of a spacecraft water supply.

CONCLUSIONS

Crew Microbiology

Aerobic microbiota of crewmembers were characteristic of healthy individuals.

Fecal anaerobic microbiota data indicated that a shift in intestinal microorganism ratios occurs in some crewmembers.

Dissemination of microorganisms between crewmembers was demonstrated by DNA fingerprinting.

Environmental Microbiology

The Mir environment is microbiologically similar to that of the Shuttle.

Microbial levels in air and on surfaces were generally within ISS acceptability limits; fungal levels tended to be higher on Mir than found on Shuttle.

Levels of microbes in hot water were within ISS acceptability limits; levels in ambient and ground-supplied water sources frequently exceeded US limits but were within Russian limits.

Analysis of surface condensation is important for environmental assessment (first inflight recovery of protozoa and dust mites).

Potential pathogens in a closed environment can increase the risk of infection in crewmembers.

Microorganisms play a key role in the biodestruction of materials and can contribute to equipment and hardware malfunctions.

PUBLICATIONS

Abstracts

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8. Mehta, S. K., Lugg, D. J., Payne, D. A., Tyring, S. K., and Pierson, D. L. 1998. Epstein-Barr Virus reactivation in spacecraft and ground-based analogs. American Society of Gravitational Biology, Houston, TX

Investigation Title: Protein Metabolism During Long-Term Space Flights

Principal Investigator(s): T. Peter Stein, Ph.D., University of Medicine & Dentistry of New Jersey; Irina Larina

Additional Investigators: Not Applicable

INVESTIGATION OBJECTIVES

1. To determine the duration of the metabolic stress response associated with space flight.
2. To determine how long it takes for protein metabolism to return to its preflight state after a long-duration mission.

PHASE 1 MISSIONS

Mir 21/NASA 2, Mir 22/NASA 3

OPERATIONAL ACTIVITIES

The changes in protein metabolism caused by space flight were measured by using the 15N-glycine method. One gram of glycine, labeled with the stable 15N nitrogen isotope, was ingested four times during Mir 21/NASA2 and three times during NASA3/Mir22. Over the next 24 hours the protein metabolism was monitored by collecting urine and saliva samples, weight measurements and dietary monitoring. In addition, preflight measurements were used as a baseline and postflight measurements were performed to determine the recovery of the protein metabolism to preflight status.

RESULTS

Status of Data Received/Analyzed: Fewer whole body protein measurements were done during space flight than initially were planned for. There is a lack of early and middle inflight data for Mir 22/NASA3 missions.

CONCLUSIONS

1. After 4 plus months in space the whole body protein synthesis rate was reduced by an average of about 31% for Mir 21/NASA 2, and 53% for Mir 22/NASA 3 subjects. The decrease was greater than predicted from bed rest studies.
2. The cumulative data suggests that whole body protein synthesis declines with time in space.

PUBLICATIONS

Not provided by the Principal Investigator.

Investigation Title: Renal Stone Risk Assessment During Long-Duration Space Flight

Principal Investigators: Peggy A. Whitson, Ph.D., NASA/Johnson Space Center; German S. Arzamazov, M.D., Institue of Biomedical Problems

Additional Investigators: Robert A. Pietrzyk, M.S., C.Y.C. Pak, M.D., and Clarence F. Sams, Ph.D.

INVESTIGATION OBJECTIVES

1. Determine the effects of exposure to microgravity on the potential for renal stone formation.
2. Determine the effect of mission duration on the potential for renal stone formation.
3. Determine how long after flight the increased risks for renal stone formation.
4. Estimate the contribution of dietary and environmental factors to the risk of renal stone formation.

PHASE 1 MISSIONS

Mir 18, Mir 21, Mir 22, Mir 25, NASA 2, NASA 3, NASA 6, NASA 7

OPERATIONAL ACTIVITIES

- 24 hour urines were collected during the pre-, in- and postflight periods.
- Diet and fluid intake were logged for the 24 hr. period prior to urine collection and during the 24 hr. urine collection.

RESULTS

Thirteen astronauts and cosmonauts participated in this investigation. Two of these subjects performed a potential renal stone countermeasure during their flight by increasing fluid intake resulting in increased daily urine output. All crewmembers attempted to meet the requirements of this study. However, due to scheduling changes, it proved difficult to collect urine at the times requested and the effects of mission duration on renal stone formation may be difficult to assess. Instances of incomplete or missing urine collections and diet logging occurred throughout this investigation to various subjects. The study recently was completed following the landing of the Mir 25 crewmembers. Sample collection and data analysis from this mission has been completed. Construction of the database from all subjects who participated in this study is in progress.

During the NASA 6 and NASA 7 missions, a novel technique for preserving urine was evaluated. Urine samples were collected onto filter cards, the cards dried and the samples stored until return to Earth for analysis. Preservation of the urinary analytes was performed at room temperature without the uses of chemical preservation, refrigeration or freezing of samples.

CONCLUSIONS

Data from short-duration Shuttle missions have indicated that exposure to microgravity alters the urinary chemistry favoring the formation of renal stones. Preliminary conclusions from the long-duration Phase 1 investigations have supported this observation and have shown:

- Increased calcium excretion in most crewmembers despite decreased dietary calcium intake.
- Decreased inflight fluid intake resulting in lower daily urinary output.
- Decreased urinary citrate, an inhibitor of calcium-containing stone formation, during an immediately after flight.
- Individual subject response to microgravity appears to play a key role in changes observed in the urinary chemistry.
- The risk of renal stone formation increases early upon exposure to microgravity and continues throughout the flight.

The two crewmembers who performed a potential renal stone countermeasure by increasing their fluid intake to increase urine output effectively reduced the risk of renal stone formation by increasing the solubility limits of the stone forming salts. These crewmembers ingested greater than 3 liters of fluid per day. This may not be a practical alternative to all crewmembers due to individual needs or schedules and does not alter the changes observed in the urinary biochemistry. However, the knowledge gained from these two subjects and from Earth based observations of renal stone sufferers has been shared with astronauts and cosmonauts. Postflight Shuttle data have now shown an increased average urine output compared to earlier Shuttle missions. In light of the occurrence of two preflight renal stones and one postflight renal stone in the U.S Space Program and one inflight stone in the Russian Space Program, continued research and countermeasure assessment is warranted.

In a addition to the renal stone risk assessment, dried urine chemistry was evaluated during the NASA 6, Mir 25 and NASA 7 missions. Overall, this new technology proved itself successful. The urinary analytes of interest to this investigation were stable for an extended period of time. This technology may enhance the capability for medical science investigations on future space missions. This technology employs minimal power, requires no sample refrigeration or freezing and has the potential to preserve a large battery of biological compounds

PUBLICATIONS

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Investigation Title: Sleep Investigations - Human Circadian Rhythms and Sleep in Space (E639)

Principal Investigator: Timothy H. Monk, D.Sc., Ph.D., University of Pittsburgh

INVESTIGATION OBJECTIVES

1. To study sleep, daytime performance and mood, oral temperature and pre and post-sleep ratings from three 12-day measurement blocks in flight.

PHASE 1 MISSIONS

NASA 4, Mir 23, Mir 24

OPERATIONAL ACTIVITIES

In each day of the 12-day measurement blocks one astronaut was to:

1. Complete a pre-sleep diary (1/day).
2. Complete a post-sleep diary (1/day).
3. Perform a simple performance battery (1/day).
4. Rate mood and alertness and take oral temperatures (5/day).

RESULTS

NASA 4

Harvest rate for acceptable data (%) was as follows:

First Block: 100% for #1, 91.7% for #2, 91.7% for #3, 90% for #4

Second Block: 100% for #1, 100% for #2, 100% for #3, 100% for #4

Third Block: 91.7% for #1, 100% for #2, 100% for #3, 96.7% for #4

Mir 23

Harvest rate for acceptable data (%) was as follows:

First Block: 95.8% for #1, 95.8% for #2 , 91.7% for #3, 78.3% for #4

Second Block: 95.8% for #1, 100% for #2, 91.7% for #3, 87.5% for #4

Third Block: 45.8% for #1, 50% for #2, 45.8% for #3, 46.7% for #4

Mir 24

Harvest rate for acceptable data (%) was as follows:

First Block: 50% for #1, 41.7% for #2 , 20.8% for #3, 32.5% for #4

Second Block: 29.2% for #1, 16.7% for #2, 16.7% for #3, 3.4% for #4

Third Block: 0% for #1, 0% for #2, 0% for #3, 0% for #4

CONCLUSIONS

NASA 4

The data indicated that for various reasons some sleep episodes were of duration five hours or less. When the days following these sleeps were examined detrimental effects were observed in alertness, mood and perceived work performance

Mir 23

The data indicated that for various reasons some sleep episodes were of duration five hours or less. When the days following these sleeps were examined detrimental effects were observed in alertness, mood and perceived work performance

Mir 24

There were insufficient data for any meaningful scientific conclusions to be drawn

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8. Monk, T. H., Buysse, D. J., & Rose, L.R. (submitted manuscript). Wrist actigraphic measures of sleep in space. (submitted to the Journal Sleep, July 1998).

Investigation Title: Sleep Investigations - Microgravity, Sleep/Wake Immune Functions (SWIF) in Humans (E710)

Principal Investigator: Harvey Moldofsky, M.D., University of Toronto, Canada

Additional Investigators: No additional investigators

INVESTIGATION OBJECTIVES

General research objectives were to determine the influence of gravity change on sleep and the immune system in crewmembers, especially as it related to well-being. Specifically, researchers expected that:

1. Space flight-related dysfunctions in health, sleep and circadian rhythms would result in a decrease in proportion of NK cells in peripheral circulation; alter plasma IL-1, IL-2, cortisol, and growth hormone (hGH); and impair NK cell cytotoxic activity.

2. Sleep, circadian rhythms, immune function, and well-being would normalize over time and become indistinguishable from sleep in normal gravity within 3 months.

PHASE 1 MISSIONS

Mir 23/NASA 4

OPERATIONAL ACTIVITIES

After the experiment was selected, it was merged at the request of NASA into a sleep experiment including scientific objectives from the University of Pittsburgh (Dr. Monk) and Harvard Medical School (Dr. Hobson.)

Pre-, in-, and postflight subjects answered questions on sleepiness, fatigue, pain and mood as well as performance that had been incorporated into a battery of questions prepared by colleagues at the University of Pittsburgh. Immunologic and endocrine assays were carried out on blood samples collected pre-, in-, and postflight. The relationship between delta or slow wave sleep activity to immune functions was examined.

RESULTS

The preflight BDC data from all crewmembers were compared to a group of healthy male volunteers to determine if sleep/wake age related immune and endocrine functions were present in middle-aged male (MAM) subjects during baseline conditions before flight on Mir vs. young healthy males (YM).

NK cytotoxicity declined during sleep versus wake in both groups, but the timing for such changes differed. There was no 24-hour mean NK difference between groups. MAM secreted less hGH over 24-hours than YM. Whereas both groups secreted their maximum hGH during sleep, there was only hGH during the daytime in YM. The cortisol level was higher in MAM, and the rise during sleep occurred later than in YM. Slow wave sleep showed minimum cortisol secretion in both groups.

Middle-aged crewmembers in preflight baseline conditions differed from young healthy males in the timing of the diurnal pattern of NK cytotoxicity, hGH, and cortisol. They also secreted less hGH and more cortisol over a 24-hour period. These hypothalamic-pituitary-adrenocortical (HPA) axis endocrine differences in healthy middle-aged men were similar to those seen in healthy older males. While the dynamic structure of NK cytotoxicity differed, there was no overall mean difference from young males.

CONCLUSIONS

Not provided by the PI.

PUBLICATIONS

No publications available.

Investigation Title: Sleep Investigations - Sleep and Vestibular Adaptation (E663)

Principal Investigator: J. Allan Hobson, M.D., Massachusetts Mental Health Center

Additional Investigators: Robert Stickgold, Ph.D., Irina Ponomareva, M.D., and Irina Larina, M.D.

INVESTIGATION OBJECTIVES

1. To design and test a portable, self applicable REM/nonREM/wake-state monitoring system with special reference to the constraints and conditions of prolonged space flight.
2. To obtain long-term data on the physiology and behavior of human sleep under prolonged microgravity conditions.

PHASE 1 MISSIONS

Mir 23/NASA 4, Mir 24/NASA 5

OPERATIONAL ACTIVITIES

One astronaut and four cosmonauts wore the Night Headband Monitor for a total of 317 nights of sleep data. Subjects recorded an average of 26 nights of sleep during the preflight period, 24 nights in flight, and 14 nights during the postflight recovery period. All told, 120 nights of sleep data were collected in flight, between the 24th and 171st day in orbit. Sixty of the 120 nights were recorded more than three months into the flight.

RESULTS

Preliminary analyses show that REM sleep was severely diminished during flight for all five subjects. Both REM time and REM % (of total sleep time) were significantly diminished (REM time, $F=20.5$, $p<0.001$; REM%, $F= 16.5$, $p<0.002$). On average, REM time was reduced by 53% and REM% by 35% in flight compared to preflight. All subjects showed at least a 40% reduction in REM time. In contrast, postflight rates were essentially the same as preflight, showing on average a 4% increase in both REM time and REM% compared to the preflight period.

There was also a decrease in total sleep time in flight ($F=7.1$, $p<0.02$). Inflight values were reduced by 27% on average, while postflight values were 0.3% higher. All subjects showed at least a 13% decrease in average nightly total sleep time. This did not result from a decrease in time in bed ($F=0.2$, $p=0.84$); subjects spent on average 4% longer in bed while in flight. Rather, it resulted from a decreased sleep efficiency ($F=24.1$, $p<0.0005$). Efficiency dropped from a mean of 89% in the preflight period to 63% in flight.

CONCLUSIONS

The Nightcap sleep monitoring system has permitted more extensive sleep recording during space flight than has been previously possible. The data collected over 6 months of flight indicate that extended space flight leads to a consistent and pronounced decrease in sleep efficiency, time spent in REM sleep, and the percent of total sleep time spent in REM sleep as measured by the Nightcap. Neither the causes nor the consequences of these alterations are clear. But the continued reduction in these values might well lead to diminished performance of crewmembers in space.

PUBLICATIONS

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Investigation Title: Enhanced Dynamic Load Sensors (EDLS) on Mir

Principal Investigator(s): Sherwin Beck, NASA/Langley Research Center

Additional Investigator(s):

INVESTIGATION OBJECTIVES

The Enhanced Dynamic Load Sensor (EDLS) experiment is designed to measure the crew-induced forces and torques imparted on the Mir habitat module's interior surfaces. The EDLS hardware measure the magnitude and frequency of the crew-induced disturbances of the Mir microgravity environment.

PHASE 1 MISSIONS

Mir 21 - Mir 24, NASA 2 - NASA 5

OPERATIONAL ACTIVITIES

- EDLS hardware (ESM and sensors) transported to Mir and installed in the Priroda module in 1996
- Approximately 20 EDLS sessions performed during NASA 2/Mir 21 missions (5/96-8/96)
- Original EDLS ESM replaced with similar ESM for MiDSE experiment (1997)
- Approximately 15 high quality EDLS sessions performed during NASA 4/Mir 22/Mir 23 missions (2/97-5/97)

The torque/force sensors were mounted in the Mir Priroda module and used as restraints by the crew in the performance of their normal work routine duties involving glovebox activities.

RESULTS

Analysis of data collected indicated that the crew loads induced on module internal structures are no greater than 70 Newtons at a frequency of range from 0 to 10 Hertz (Hz). During the initial arrival periods, crew induced loads are higher but as space adaptation period progressed, these loads were reduced. A crewmember learns to reduce his/her effort needed to perform intended motions, thus reducing the loads imparted to the spacecraft structure.

CONCLUSIONS

Not provided by PI.

PUBLICATIONS

1. Lofton R, Conley C. International Space Station Phase 1 Risk Mitigation and Technology Demonstration Experiments. 48Th International Astronautical Congress; 1997 Oct 6-10; Turin, Italy; International Astronautical Federation.

Investigation Title: Inventory Management System (IMS)

Principal Investigator(s): Robert J. Hanley, NASA/ Johnson Space Center; Thomas D. Akers, NASA/ Johnson Space Center; Ronald M. Sega, NASA/ Johnson Space Center

Additional Investigator(s):

INVESTIGATION OBJECTIVES

1. To develop and evaluate the operational techniques associated with the use of IMS software and BCR in conjunction with flown checklists to document and maintain inventory control of equipment transferred between the Shuttle and Mir Space Station.
2. To evaluate the use of bar code labels on stowage locations and equipment.
3. To evaluate the use of preflight electronic stowage documentation.

PHASE 1 MISSIONS

STS-79, NASA 4

OPERATIONAL ACTIVITIES

Not available at this time.

RESULTS

Not available at this time.

CONCLUSIONS

Not available at this time.

PUBLICATIONS

Not available at this time.

Investigation Title: Mir Audible Noise Measurement (MANM)

Principal Investigator(s): C. Parsons, NASA/Johnson Space Center

Additional Investigator(s):

INVESTIGATION OBJECTIVES

1. To determine where acoustic mitigation may be required to ensure crew protection if Russian hardware exceeds noise level limits.

PHASE 1 MISSIONS

STS-74

OPERATIONAL ACTIVITIES

The hardware (sound level meter, one-third octave filter, microphone, noise dosimeter, audio recorder, and headphones) was taken to the Mir and positioned in a central location within a designated module. Crewmembers noted the location using the audio recorder and took sound level measurements. Questionnaires were also completed during flight to document the crewmembers' subjective acceptability of the measured noise levels.

RESULTS

The results of this experiment show that the US standard noise criteria (NC) 50 curve level was exceeded at the majority of the measurement locations. Overall, the crew's subjective impressions of the Mir acoustic environment was favorable, though a longer term evaluation of the environment may provide more valuable data.

CONCLUSIONS

Not provided by PI.

PUBLICATIONS

1. Lofton R, Conley C. International Space Station Phase 1 Risk Mitigation and Technology Demonstration Experiments. 48Th International Astronautical Congress; 1997 Oct 6-10; Turin, Italy; International Astronautical Federation.
2. Bieirie J. Mir Acoustic Environment. 26Th International Conference on Environmental Systems; 1996 Jul 8-11; Monterey, California; Society of Automotive Engineers.

Investigation Title: Mir Electric Field Characterization (MEFC)

Principal Investigator(s): M. A. Chavez, NASA/Johnson Space Center; G. D. Arndt, P. H. Ngo

INVESTIGATION OBJECTIVES

The primary objective of the Mir Electric Fields Characterization (MEFC) Experiment is to sample the RF environment in low Earth, high inclination orbits.

The secondary objective of the MEFC experiment is to measure the electric field intensity in various Mir modules to get typical values of field intensity within a spacecraft.

PHASE 1 MISSIONS

STS-79, STS-81, STS-84

OPERATIONAL ACTIVITIES

External signals measured through Orbiter overhead window. Mir internal RF environment measured within Priroda and Core modules.

RESULTS

Data was collected during STS-79 and STS-81 which provides a sample of the RF environment in low Earth, high inclination orbits and within the Priroda module.

CONCLUSIONS

Active frequency bands were identified and the field strength in those bands was seen to be moderate. Due to a hardware failure during STS-84, limited data was collected aboard Mir; however, data collected aboard the Priroda module during STS-79 and STS-81 showed a benign internal RF environment, suggesting good shielding effectiveness to the external environment.

PUBLICATIONS

Not provided by PI.

Investigation Title: Mir Environmental Effects Payload (MEEP)

Principal Investigator(s): Buck Gay, NASA/Johnson Space Center

Additional Investigator(s):

INVESTIGATION OBJECTIVES

1. To assess the magnitude of molecular contamination in ISS critical exterior surfaces in the space environment.
2. To quantify the performance and degradation rate of candidate and selected ISS exterior surface materials.

PHASE 1 MISSIONS

STS-76, STS-79, STS-81, STS-84, STS-86, NASA 6

OPERATIONAL ACTIVITIES

Not provided by PI.

RESULTS

See Passive Optical Sample Assembly #1 and #2, Orbital Debris Collector, and Polished Plate Micrometeoroid Detector.

CONCLUSIONS

Not provided by PI.

PUBLICATIONS

None.

Investigation Title: Mir Structural Dynamics Experiment (MiSDE)

Principal Investigator(s): Hyoung-Man Kim, Ph.D., Boeing

Additional Investigators: Sergei Simakov, Ph.D., Vyatcheslav Mezhin, and Mohamed Kaouk, Ph.D.

INVESTIGATION OBJECTIVES

1. Demonstrate the feasibility of correlating math models of large space structures by on-orbit modal testing.

PHASE 1 MISSIONS

NASA 3/STS-81, NASA 4/STS-84, NASA 5/STS-86, NASA 6.

OPERATIONAL ACTIVITIES

The experiment was performed from November 1996 to December 1997 and the MiSDE data was obtained from a total of 45 test sessions: 25 with the Mir alone and 20 with the Shuttle-Mir mated.

RESULTS

Modal parameters (frequency, damping, and mode shape) were extracted from a total of 35 transient events and model refinements were performed on a total of six configurations using the extracted modes.

CONCLUSIONS

The results from this study demonstrated that on-orbit modal testing and model refinement for large space structures are feasible within operational constraints.

PUBLICATIONS

1. Kim, H.M. and Kaouk, M., "Mir Structural Dynamics Experiment: First Phase Test and Model Refinement," *Proc. 40th AIAA SDM Conference,* St. Louis, MO, Paper No. AIAA-99-1453, April 1999.
2. Kim, H.M. and Kaouk, M., *Final Report: Mir Structural Dynamics Experiment,* The Boeing Company, Dec. 1998.
3. Kim, H.M. and Kaouk, M., "Mir Structural Dynamics Experiment: First Phase Test and Data Analysis," *Proc. 39th AIAA SDM Conference,* Long Beach, CA, Paper No. AIAA-98-1721, April 1998.
4. Kim, H.M. and Bokhour, E.B., "Mir Structural Dynamics Experiment: A Flight Experiment Development," *Proc. 38th AIAA SDM Conference,* Kissimmee, FL, Paper No. AIAA-97-1169, pp. 577-585, April 1997.

Investigation Title: Mir Wireless Network Experiment (MWNE)

Principal Investigator(s): Yuri Gawdiak, NASA/Ames Research Center

Additional Investigator(s):

INVESTIGATION OBJECTIVES

1. To evaluate the function of this system as part of remote communications planning for the ISS
2. To test commercial radio frequency wireless data links and mobile computer equipment to determine effective ranges and data throughput rates
3. To investigate the effects of radiation on advanced computer systems
4. To investigate human/computer interaction factors in a microgravity environment

PHASE 1 MISSIONS

STS-76

OPERATIONAL ACTIVITIES

The system was launched on STS-74. The experiment was performed aboard STS-76 and Mir Spektr in March, 1996.

RESULTS

- Sustainable Network throughput: 200-400 kbits/second, capable of supporting MANM requirements
- Operating range: within two adjacent station modules
- Passed flight qualification, electromagnetic compatibility and safety review.
- No computer failures during operation after 4 months of stowage aboard Mir (Spektr location 210)
- Reduced power radios will work, but coverage and range is affected
- Radios had mechanical capacitor adjustment drift due to launch vibration resulting in 10% decreased throughput.

CONCLUSIONS

Not provided by PI.

PUBLICATIONS

1. Lofton R, Conley C. International Space Station Phase 1 Risk Mitigation and Technology Demonstration Experiments. 48Th International Astronautical Congress; 1997 Oct 6-10; Turin, Italy; International Astronautical Federation.

Investigation Title: Optical Properties Monitor

Principal Investigator(s): Donald R. Wilkes, AZ Technology

Additional Investigators: Edgar R. Miller, James M. Zwiener, and Jean M. Bennett

INVESTIGATION OBJECTIVES

1. To study the effects of the natural and induced environment around the Mir on Spacecraft Materials.

PHASE 1 MISSIONS

STS-81 - Launch; STS-89 - Retrieval

OPERATIONAL ACTIVITIES

April 1997 - EVA Deployment

April 1997 - January 1998 - Operation

January 1998 - EVA Retrieval

RESULTS

The OPM performed very well for the Mir mission and has provided unique data on the behavior of materials around a Space Station.

CONCLUSIONS

Data gathered by the OPM has provided important data for ISS and should be reflown on ISS to assess the environment and materials performance during early ISS activities.

PUBLICATIONS

1. ISS/Mir Space Environmental Effects Experiments; ISS Contamination/Materials Technical Interchange Mtg: January 13, 1998.
2. Optical Properties Monitor; 2nd ISS Phase 1 Research Program Interim Results Symposium; April 2, 1998.
3. Optical Properties Monitor; Space Environment and Effects Flight Experiments Workshop; MSFC, June 23, 1998.
4. In-Situ Materials Experiments on the Mir Station; SPIE 43rd Annual Meeting; July 19, 1998.
5. Optical Properties Monitor; ISS Optical Property Degradation Review Technical Interchange Meeting; September 29, 1998.
6. Optical Properties Monitor; 3rd ISS Phase 1 Research Program Interim Results Symposium; November 4, 1998.
7. The Mir Environment and Material Effects as Observed on the OPM Experiment; 37th AIAA Aerospace Sciences Mtg; Jan. 1999.

Investigation Title: Orbital Debris Collector (ODC)

Principal Investigator(s): Freidrich Horz, Ph.D., NASA/Johnson Space Center

Additional Investigator(s): Not provided by PI

INVESTIGATION OBJECTIVES

The objectives for the ODC experiment were: to measure the potential risks of a high inclination Earth orbit by collecting samples of space debris which collides with the Mir Space Station and to characterize the types of collisions which occur in orbit and the potential for damage to the Mir and the future International Space Station caused by such collisions.

PHASE 1 MISSIONS

STS-76, NASA 2 - NASA 5, STS-86

OPERATIONAL ACTIVITIES

The ODC experiment was delivered to the Mir Space Station and mounted on the Priroda module during an EVA by STS-76 Shuttle astronauts. PPMDC remained outside the Mir Space Station, requiring no crewtime during the NASA 2, NASA 3, NASA 3, NASA 4, and NASA 5 missions. During an EVA by the STS-86 Shuttle crew, the experiment was retrieved and returned to Earth for analysis.

RESULTS

Not provided by PI

CONCLUSIONS

Not provided by PI

PUBLICATIONS

Not provided by PI

Investigation Title: Passive Optical Sample Assembly (POSA #1 and #2))

Principal Investigator(s): Jim Zwiener (POSA #1), NASA/Marshall Space Flight Center; Gary Pippin (POSA #2), Boeing Defense & Space Group

Additional Investigator(s):

INVESTIGATION OBJECTIVES

1. To identify the locations, dimensions, and characteristics of the damage at micrometeoroid and debris impact sites (POSA #1).
2. To assess the magnitude of particulate and molecular contamination during exposure to the Mir environment on candidate and selected ISS external surface materials (POSA #2).
3. To obtain data to help quantify the performance and degradation rate of candidate materials (POSA #2).

PHASE 1 MISSIONS

STS-76, STS-79, STS-81, STS-84, STS-86

OPERATIONAL ACTIVITIES

- All four MEEP experiments delivered to Mir by STS-76
- Successfully deployed on March 26th and 27th, 1996 during STS-76
- MEEP successfully retrieved on October 1, 1997 during STS-86 mission and returned to the ground.
- The MEEP was exposed to the Mir external space environment for 18 months

RESULTS

Contamination Detected on MEEP Experiments

POSA #1 contamination: space facing side >6000 angstroms; Mir facing side ~350 angstroms

POSA #2 contamination: visible contamination on space facing side; no visible contamination on Mir facing side.

Characteristics of Contamination Detected

POSA #1, space and Mir facing sides: deposit uniform in texture; varies in thickness. Identified as a silicate.

POSA #2, space facing side: mostly splatter or droplet contamination; identified as human waste

Potential Sources of Contamination Detected on MEEP Experiments

POSA #1, space facing side: stored solar array on docking module; silicone offgassing, converted to a silicate during exposure to atomic oxygen

POSA #2, space facing side: waste water dumps or leaks; either Mir or Shuttle (evaluations of potential sources are continuing)

CONCLUSIONS

- Contamination is a potentially serious threat to lifetime performance of critical ISS exterior materials
- Thermal properties of baseline ISS materials all indicated a sensitivity to contamination thickness
- Contamination depositions and effects are a function of material type, exposed surface are time, line of sight, distance, surface temperature, and local natural environmental elements (AO, UV interactions)

PUBLICATIONS

None.

Investigation Title: Polish Plate Micrometeoroid Debris (PPMD) Collector

Principal Investigator(s): William Kinard, NASA/Langley Research Center

Additional Investigator(s): Not provided by PI

INVESTIGATION OBJECTIVES

The objectives of the PPMDC experiment were: to gain a better understanding of the types of debris found at high inclination Earth orbit, to allow for better determinations of methods of protection needed for spacecraft orbiting the Earth at high inclinations, and to identify methods needed to control harmful debris orbiting the Earth.

PHASE 1 MISSIONS

STS-76, NASA 2 - NASA 5, STS-86

OPERATIONAL ACTIVITIES

The PPMDC experiment was delivered to the Mir Space Station and mounted on the external docking module during an EVA by STS-76 Shuttle astronauts. PPMDC remained outside the Mir Space Station, requiring no crewtime during the NASA 2, NASA 3, NASA 3, NASA 4, and NASA 5 missions. During an EVA by the STS-86 Shuttle crew, the experiment was retrieved and returned to Earth for analysis.

RESULTS

Not provided by PI

CONCLUSIONS

Not provided by PI

PUBLICATIONS

Not provided by PI

Investigation Title: Shuttle-Mir Alignment Stability Experiment (SMASE)

Principal Investigator(s): Russell E. Yates, NASA/Johnson Space Center; S. Shitov, Ph.D., RSC/Energia

Additional Investigator(s):

INVESTIGATION OBJECTIVES

1. To explore the human factor considerations of the Mir in regard to how forces exerted by normal crew activity affect the Mir structure and its navigational system.

PHASE 1 MISSIONS

STS-71, STS-74, STS-76, STS-79 (docked phase only)

OPERATIONAL ACTIVITIES

Shuttle and Mir vehicle attitude data were collected during multiple three-hour data collection periods while the two vehicles were docked. Navigational-dependent events were, including attitude thruster firings, Inertial Measurement Unit (IMU) alignments, and star tracker data takes occurred. The data from the experiment was used to determine the stability of and causes of any unexpected instability between the Shuttle and Mir navigation systems.

RESULTS

Results have shown that the measured transformation between the Shuttle and the Mir Space Station was within 0.3 degrees of preflight predictions. Typically, the relative stability between the two vehicles was about 0.6 degrees root mean square. The stability was excellent, considering attitude time tag errors were as large as 2.5 seconds. This experiment has provided data for the validation of analytical tools that will be used to predict the transformation between U.S. and Russian segments of the ISS.

CONCLUSIONS

The stability data indicates that Russian vehicle attitude data will meet the U.S. segment accuracy requirement of 0.5 degrees/axis. Transferring attitude data between U.S. and Russian segments is feasible and will benefit the ISS.

PUBLICATIONS

1. Lofton R, Conley C. International Space Station Phase 1 Risk Mitigation and Technology Demonstration Experiments. 48Th International Astronautical Congress; 1997 Oct 6-10; Turin, Italy; International Astronautical Federation.

Investigation Title: Space Portable Spectroreflectometer (SPSR)

Principal Investigator(s): Ralph Carruth, NASA/Marshall Space Flight Center

Additional Investigators: Jim Zwiener, Rachel Kamanetzky, Don Wilkes, and Stanislav Naumov

INVESTIGATION OBJECTIVES

Direct measurement of solar absorptivity of Mir thermal radiators to determine degradation due to years of exposure to the space environment and contamination; Obtain data applicable to ISS long-term degradation; Demonstrate portable instrument could be utilized EVA

PHASE 1 MISSIONS

NASA 6 Operational and Returned on NASA 7

OPERATIONAL ACTIVITIES

Not provided by PI.

RESULTS

SPSR was utilized during one EVA and data was acquired from one of the KVANT II radiators; the rigidizing tether, for stability, did not fit handrail and the SPSR display faded out which affected data.

CONCLUSIONS

Mir radiator surface was relatively clean of contaminants; there was some degradation of solar absorptivity (as expected) but difficult to quantify due to problems with the rigidizing tether and the SPSR display; data appeared to indicate that value was within russian end of life predictions.

PUBLICATIONS

1. "In-Situ Materials Experiments on the Mir Station," SPIE Vol. 3427
2. "Space Portable Spectroreflectometer (SPSR) Investigation on Mir Space Station," AIAA 99-0101

Investigation Title: Test of Portable Computer System (TPCS) Hardware

Principal Investigator(s): Rodney L. Lofton, NASA/Johnson Space Center

Additional Investigators: Andrew L. Klausman

INVESTIGATION OBJECTIVES

The TPCS experiment was designed to determine the quantity of Single Event Upsets (SEUs) that occur on ISS Portable Computer System hardware due to the radiation environment at the ISS orbital inclination. The TPCS hardware consisted of a COTS IBM-760ED laptop computer with 48 Mbytes of RAM, a power supply unit, a floppy disk drive, two hard drives, and associated power, data, and video cables.

PHASE 1 MISSIONS

NASA 6, NASA 7

OPERATIONAL ACTIVITIES

NASA 6 (7) crewmember unstowed and set up the TPCS hardware at two week intervals throughout a mission. The crewmember activated the SEU software (Super Memory Checker) and ran the software continuously for approximately 8 hours per session, recording "upsets"

RESULTS

All hardware and software worked as expected.

Super Memory Checker (SMEM) software program ran 102 hours during NASA 6 and 76.5 hours during NASA 7.

Total number of SEUs measured: 9 during NASA 6, 5 during NASA 7.

CONCLUSIONS

The IBM 760ED laptop computer seems to be well suited for space-based tasked than predecessor laptops. The off-the-shelf laptor's internal memory is not radiation harden, so random memory bit changes can be expected on the order of 9 per 100 hours of operation.

PUBLICATIONS

1. "Results of Risk Mitigation Experiment 1332 for Space Shuttle and Space Station Mir Missions", Final Report 1998.

Investigation Title: Water Microbiological Monitor (WMM)

Principal Investigator(s): Duane L. Pierson, Ph.D., NASA/Johnson Space Center

Additional Investigators: None listed.

INVESTIGATION OBJECTIVES

1. To detect and quantify the bacterial count in Mir potable water from three sources: the hot potable water dispenser, the cold potable water dispenser and the SVO-ZV (ground-supplied water) dispenser on board Mir.

PHASE 1 MISSIONS

Mir 22/NASA 3, Mir 23/NASA 4, Mir 25/NASA 5

OPERATIONAL ACTIVITIES

Hot, cold and SVO-ZV water was collected on flight days 15, 55 and 135 to process microbial capture devices (MCD) and placed in an incubator at 25 to 37 degrees Celcius. The crewmember performed a colony count and video recorded (approximately 1 minute of film making sure that the writing on the device was focused in the field of view) the MCD two and five days after the initial collection. After examination, the MCDs were returned to the incubator. Visual examination of each MCD was performed and the bacterial colony count was compared to the comparison card. Findings were recorded on data recording sheets and on the MCD. MCDs were examined for 5 days. After 5 days the MCDs were stowed in a returning kit for return to Earth. After return to Earth the bacterial colonies were identified.

RESULTS

Information not currently available.

CONCLUSIONS

Information not currently available.

PUBLICATIONS

Information not currently available.

Investigation Title: Volatile Organic Analyzer (VOA)

Principal Investigator(s): John T. James, Ph.D., NASA/Johnson Space Center

Additional Investigator(s): Thomas Limero

INVESTIGATION OBJECTIVES

1. Evaluate VOA operation in microgravity: heating and cooling profiles, gas chromatography temperature programming, scrubber capability (halons, freons, moisture), and VOA on-orbit procedures.

PHASE 1 MISSIONS

STS-81, STS-89

OPERATIONAL ACTIVITIES

Not provided by PI.

RESULTS

Heating and Cooling: VOA/RME maintained excellent thermal control. Gas Chromatography Retention Times showed excellent reproducibility in flight and compared to ground-based databases. Excellent reproducibility of Ion Drift Times was observed.

Scrubbing Capacity: Moisture/contaminant scrubbing was excellent. Halon scrubbing was not sufficient.

VOA On-orbit Procedures: Nominal procedures (remote and automatic samples) were satisfactory. IFM procedure was very difficult.

Mechanical/Electrical Design: All mechanical devices (flows, valves, etc.) performed nominally. Electrical devices (heaters, valve drivers, computers, etc.) worked nominally except for code problem fixed by scandisk. Significant carryover was identified as coming from the trap/inlet.

Software/Database: All method files performed nominally. Data analysis programs generally performed well. Algorithm/database issues were identified.

CONCLUSIONS

VOA hardware components and software successfully tested in microgravity. Proper calibration will lead to accurate identification and quantitation of target compounds. Minimum impact to crew for on-orbit nominal procedures.

PUBLICATIONS

None.

Investigation Title: Volatile Removal Assembly (VRA)

Principal Investigator(s): Donald Holder

Additional Investigator(s):

INVESTIGATION OBJECTIVES

1. To assess the operability and performance of the VRA process in microgravity. On-line data will be collected during normal steady-state operation. Water samples collected by the crew will be analyzed on the ground to supplement on-orbit data.

PHASE 1 MISSIONS

STS-89

OPERATIONAL ACTIVITIES

Not available at this time.

RESULTS

Not available at this time.

CONCLUSIONS

Not available at this time.

PUBLICATIONS

Not available at this time.

Investigation Title: Water Quality Monitor (WQM)

Principal Investigator(s): Richard L. Sauer, P.E., NASA/Johnson Space Center

Additional Investigators: Yuri Sinyak, Ph.D.

INVESTIGATION OBJECTIVES

1. To demonstrate the Total Organic Carbon (TOC) Analyzer technology in microgravity and determine whether the design meets the analytical requirements for monitoring the quality of International Space Station (ISS) reclaimed water.

2. To evaluate real-time the quality of the reclaimed potable water on Mir.

PHASE 1 MISSIONS

STS-81

OPERATIONAL ACTIVITIES

The Water Quality Monitor (WQM) experiment was expected to provide a demonstration of the technology for measuring total organic carbon, total inorganic carbon, total carbon, pH and conductivity on orbit. The WQM hardware consisted of a water sampling kit, a stowage kit and a TOC Analyzer. The sampling kit contained the supplies needed to collect water from the Mir water ports, plastic bags, 25 ml water sample syringes (used to insert samples into the TOC Analyzer), pens for labeling the samples and disinfectant wipes. The stowage kit contains items needed to support the analysis of water samples in the TOC Analyzer such as data and power cables, test sample syringes and data cards. The TOC Analyzer was a portable electronic box. The crew inserted either test solution or Mir water via syringe into the TOC Analyzer using an access door on the front panel. The crewmember then pushed a button on the instrument's front panel to begin automatic analysis of the sample. Water samples were also archived for analysis on Earth; results were compared to on-orbit data, which was intended to help evaluate the performance of the TOC Analyzer in microgravity.

RESULTS

Information not currently available.

CONCLUSIONS

Information not currently available.

PUBLICATIONS

Information not currently available.

Investigation Title: Ambient Diffusion-Controlled Protein Crystal Growth

Principal Investigator: Daniel C. Carter, Ph.D., New Century Pharmaceuticals, Inc.

Additional Investigators: Dr. John Rosenberg, Dr. Mark Wardell, Dr. Gottfried Wagner, Dr. Gerard Bunick, Dr. Franz Rosenberger, Dr. Bill Thomas, Dr. B. C. Wang, Dr. Jean-Paul Declercq, Dr. Louis Delbaere, Dr. Don Frazier, and Dr. Bill Stallings

INVESTIGATION OBJECTIVES

1. Evaluate experiment/hardware approach and produce high quality protein crystals for scientific applications.

PHASE 1 MISSIONS

NASA 2 - NASA 5, NASA 7

OPERATIONAL ACTIVITIES

Not provided by PI.

RESULTS

Exceptionally large crystals of lysozyme (1.25 cm), albumin (0.8 to 1.0 cm), as well as the largest examples of crystals of the nucleosome core particle and histone octomer were produced. Crystals of the membrane associated protein bacteriorhodopsin were of improved size and quality. Additionally, crystals of several proteins have proved suitable for analysis and structure determination by neutron diffraction. This has produced the first completed protein structure determined by neutron diffraction as a direct result of microgravity (J. X. Ho, et al. unpublished results). To date, largely because of limitation in crystal size, only approximately one dozen protein structures have ever been determined by neutron diffraction. Experience gained from flight and ground-based experiments has proven essential to the proper utilization of the technology, as well as successful operations during periods of long-duration microgravity. One consequence of this success is that the technology has been licensed (1) and the hardware is now available commercially for ground-based applications.

Research involving a multi-diciplinary internationally recognized group of scientists has made key strides, both experimentally and theoretically, toward understanding the underlying role of microgravity in production of crystals with improved size and quality (2). A summary of the experiments and results has been published (3). Improved versions of the hardware have been selected through a recent NRA which will pave the way for future experiments on the International Space Station.

CONCLUSIONS

DCAM, a specially designed hardware for the Mir experiment series, has proven to be a highly successful and valuable concept for the production of unusually large protein crystals. As a consequence, DCAM appears to have eliminated the barrier to the routine production of macroscopic centimeter sized protein crystals for neutron analysis. Insight into the role of microgravity in protein crystal growth promises to guide future applications.

PUBLICATIONS

1. D. C. Carter U. S. Patent No. 5,641,681 (1997).
2. D. C. Carter, K. Lim, J. X. Ho, B. S. Wright, P. D. Twigg, T. Y. Miller, J. Chapman, K. Keeling, J. Ruble, P. G. Vekilov, B.R. Thomas, F. Rosenberger, and A. A. Chernov, “Lower dimer impurity incorporation may result in higher perfection of HEWL crystals grown in microgravity: A case study,” J. Cryst. Growth, in press (1998).
3. D. C. Carter, B. Wright, T. Miller, J. Chapman, P. Twigg, K. Keeling, K. Moody, M. White, J. Click, J. R. Ruble, J. X. Ho, L. Adcock-Downey, G. Bunick, J.Harp, “Diffusion-controlled Crystallization Apparatus for Microgravity (DCAM): Flight and Ground-based Applications,” J. Cryst. Growth, in press (1998).

Investigation Title: Angular Liquid Bridge Experiment in the Microgravity Glovebox (ALB)

Principal Investigator(s): Paul Concus, University of California at Berkeley

Additional Investigators: Robert Finn, Stanford University and Mark Weislogel, NASA Lewis Research Center

INVESTIGATION OBJECTIVES

The objective of this experiment is to explore the behavior of liquid-vapor interfaces in a low-gravity environment, by comparing experimental with mathematical results that predict major shifts of liquid with small changes in container configuration or in contact angle. The particular configurations investigated were those of a liquid between parallel and tilted plates.

PHASE 1 MISSION

Mir 23/NASA 4

OPERATIONAL ACTIVITIES

Two test vessels were flown: The Movable Wedge Vessel and the Angular Liquid Bridge Vessel. Both vessels were constructed largely of acrylic plastic with aluminum fittings. Liquid drops were deployed on the plate surfaces by the crew member, in some cases after a fluoropolymer coating to achieve the desired wetting properties had been applied. Intersection angles between the plates were varied, and the liquid behavior was recorded on videotape, along with verbal comments by the crew member.

RESULTS

The on-board procedures for applying coating to the plates worked successfully to achieve desired contact angles. Essentially all drops were deployed in a controlled fashion and exhibited a high degree of symmetry, despite drop sizes with diameters as large as 20 mm. Nevertheless, sufficient time to overcome hysteresis was not always allowed and additionally vessel tapping was not always introduced to initiate drop reorientation, so that the information obtained on drop transitions between the various configurations was incomplete.

CONCLUSIONS

The procedure employed for on-board coating of the plates is effective and can be a useful tool for other space experiments. The experiment suffered, however, from lack of availability from Mir for communication between the ground-based investigators and the crew member during the course of the experiment.

PUBLICATIONS

1. P. Concus and R. Finn, Discontinuous behavior of liquids between parallel and tilted plates, Phys. Fluids, 10 (1998), pp. 39-43.
2. P. Concus, R. Finn, and J. McCuan, A discontinuous dependence of liquid bridge configurations, Preprint PAM727, Center for Pure and Applied Mathematics, Univ. California, Berkeley, 1998, submitted Zeit. Anal. Anwend.
3. R. Finn, J-T. Chen, and E. Miersemann, Capillary surfaces in wedge domains: behavior at the vertex, continuity and discontinuity, asymptotic expansions, Univ. Leipzig preprint, 1998, submitted to J. Math. Pures Appl.
4. R. Finn and J. McCuan, Vertex theorems for capillary drops on support planes, MSRI preprint 1997-077, to appear in Mathematische Nachrichten.

Investigation Title: Binary Colloidal Alloy Tests (BCAT1, BCAT2)

Principal Investigator: Dave A. Weitz, Ph.D., University of Pennsylvania

Additional Investigators: Prof. P.N. Pusey and Dr. P.N. Segre

INVESTIGATION OBJECTIVES

Study growth of binary colloidal alloy crystals and colloid-polymer gels by photography to assist in optimizing sample choice for future experiments, Physics of colloids in Space, scheduled to fly in the express rack on the ISS. The glovebox experiments help mitigate the risk of the ISS experiment.

PHASE 1 MISSIONS

Mir

OPERATIONAL ACTIVITIES

Photograph 10 samples about twice a day for 90 days; video colloid-polymer gels with low magnification microscope for several hours.

RESULTS

Pictures of binary colloid alloys obtained; video of colloid-polymer gels obtained.

CONCLUSIONS

Collapse of colloid polymer gels that is observed on the ground was confirmed to be due to gravity. In microgravity, no collapse was observed. Binary colloidal alloys were observed to grow more rapidly in microgravity than on Earth, and the concentration that yielded the best results was observed to be different than on the ground. This is essential information for judicious choice of samples for PCS. It also indicates that gravity plays a subtle role in the crystallization which is, as yet, not understood.

PUBLICATIONS

NASA report, and several in preparation.

Investigation Title: Biochemistry of 3-D Tissue Engineering - BTS

Principal Investigator(s): Timothy Hammond, M.B., B.S, Tulane Environmental Astrobiology Center

Additional investigators: Thomas J. Goodwin M.A. and James H. Kaysen Ph.D.

INVESTIGATION OBJECTIVES

Primary engineering objective: hardware validation.

i. To determine the engineering perfomance of the BSTC during 105 days of inflight cell culture.

Secondary biotechnology objectives:

i. To determine if cells will grow and propagate in culture in microgravity.

ii. To validate procedures for cell transfer, refeeding and culture splitting in microgravity.

iii. To investigate the mechanisms of differentiation of rat renal cells growing in microgravity culture.

PHASE 1 MISSIONS

STS-86 to Mir with STS-89 return of samples.

OPERATIONAL ACTIVITIES

I-STAT analysis of culture conditions.

RESULTS

F01. The BSTC supports cell culture in microgravity for prolonged periods.

F02. Cells will grow and propagate in culture in microgravity.

F03. Cell transfer, refeeding and culture splitting is efficacious in microgravity.

F04. The mechanisms of differentiation of rat renal cells growing in microgravity culture and being analyzed.

CONCLUSIONS

We have validated the engineering performance of the BSTC as flight hardware to support cell culture in microgravity, and identified components which require refurbishing. Cells grow and propagate in culture in microgravity, where cell transfer, refeeding and culture splitting can be performed with efficiency.

Mid experiment de obligation of funds for a flight experiment is devastating to timely completion of the analysis.

PUBLICATIONS

Submitted Nature Medicine.

Investigation Title: Biotechnology System (BTS) CoCulture (COCULT)

Principal Investigator(s): Elliot M. Levine, Ph.D., Wistar Institute

Additional Investigators: Thomas Goodwin, NASA Johnson Space Center

INVESTIGATION OBJECTIVES

1. Demonstrate the ability to culture cells into tissues in the Mir environment, with regard to nominal operating procedures for Space Station.

PHASE 1 MISSIONS

NASA 7

OPERATIONAL ACTIVITIES

Human breast cancer cells and endothelial cells were inoculated on the ground at KSC and the culture transported by the Shuttle to Mir and allowed to grow during the NASA 7 mission.

RESULTS

At present, data analysis and evaluation is in progress. The samples are being processed.

CONCLUSIONS

No conclusions

PUBLICATIONS

No publications

Investigation Title: Biotechnology System (BTS) Diagnostic Experiment

Principal Investigators: Steven R. Gonda, Ph.D., NASA/Johnson Space Center

INVESTIGATION OBJECTIVES

Verify and validate the Data Acquisition and Control System for the BioTechnology Facility on ISS. DACS is hardware, firmware and software designed to monitor, operate, and control experiment specific payloads and Facility systems, and to capture and archive experiment data and hardware performance data.

PHASE 1 MISSIONS

Increment	Location	Duration	Facility Components
Pre-2	*Spectr* Module	105 days	Passive PCMCIA Card
2	*Priroda*/BTS Facility	156 days	Powered DACS
3	*Priroda*/BTS Facility	130 days	Powered DACS with Bioreactor
4 & 5	*Priroda*/BTS Facility	263 days	Powered DACS
7	*Priroda*/BTS Facility	142 days	Powered DACS and Powered DACS with Bioreactor

OPERATIONAL ACTIVITIES & PRELIMINARY CONCLUSIONS

Increment	Facility Hardware	Activity Summary
Pre-2	Passive PCMCIA Card	• SRAM cards in stowage are susceptible to radiation induced SEU corruption • Unpowered Flash PC-Cards in stowage are immune to SEU corruption at MIR radiation levels
2	Powered DACS	• Powered Flash PC-Cards are immune to SEU corruption at MIR radiation levels • Verified DACS integrated operation
3	Powered DACS with Bioreactor	• Verified DACS control of experiment specific hardware • Verified operation of DACS RRS
4 & 5	Powered DACS	• Extended previous results for larger capacity flashcards and longer duration operations • Detection of DRAM SEUs
7	Powered DACS and Powered DACS with Bioreactor	• Verified DACS control of experiment specific hardware, including RRS • Verified capability of DACS RRS to repair, monitor and protect SRAM PC-Cards in-flight • Extended and reinforced previous results

PUBLICATIONS

Not provide by PI.

Investigation Title: Biotechnology System (BTS) Facility Operations

Principal Investigators: Steven R. Gonda, Ph.D., NASA/Johnson Space Center

INVESTIGATION OBJECTIVES

In order to conduct Risk Mitigation for the BioTechnology Facility on the ISS, the BTS was designed and flown on the Mir Space Station. The purpose of the BTS was multi-fold and included:

1. Demonstration of technology and systems to support biotechnology investigations.
2. Validation of BTF concepts and systems through long-duration operations.
3. Verification of BTF operational and training procedures.
4. Verification of the launch and transfer of operating experiments between orbiting spacecraft.
5. Fundamental Science investigations.

PHASE 1 MISSIONS

Increment	Location	Duration	Facility Components
Pre-2	*Spectr* Module	105 days	Passive PCMCIA Card
2	*Priroda*/BTS Facility	156 days	Powered DACS
3	*Priroda*/BTS Facility	130 days	Powered DACS with Bioreactor
4 & 5	*Priroda*/BTS Facility	263 days	Powered DACS
6	*Priroda*/BTS Facility	140 days	Bioreactor
7	*Priroda*/BTS Facility	142 days	Powered DACS and Powered DACS with Bioreactor

OPERATIONAL ACTIVITIES

Increment	Facility Hardware	Activity Summary
Pre-2	Passive PCMCIA Card	• SRAM cards in stowage are susceptible to radiation induced SEU corruption • Unpowered Flash PC-Cards in stowage are immune to SEU corruption at MIR radiation levels
2	Powered DACS	• Powered Flash PC-Cards are immune to SEU corruption at MIR radiation levels • Verified DACS integrated operation
3	Powered DACS with Bioreactor	• Verified DACS control of experiment specific hardware • Verified operation of DACS RRS
4 & 5	Powered DACS	• Extended previous results for larger capacity flashcards and longer duration operations • Detection of DRAM SEUs
7	Powered DACS and Powered DACS with Bioreactor	• Verified DACS control of experiment specific hardware, including RRS • Verified capability of DACS RRS to repair, monitor and protect SRAM PC-Cards in-flight • Extended and reinforced previous results

RESULTS

Mir/BTS Technology and Systems Demonstration:

- Data Acquisition and Control System (ECC, Flashcards, recovery software)
- Gas Supply Module
- System performance, maintenance and extended operation
- Evaluation of monitoring (video, microscope) systems
- Experiment change-out procedures
- Data Acquisition, storage and downlink
- Bioreactor design and operations
- Bioreactor sensors and automation control systems
- Cell culture operations

Media preparation and storage

CONCLUSIONS

Pending completion of analysis in FY99.

PUBLICATIONS

Not provided by PI.

Investigation Title: Canadian Protein Crystallization Experiment (CAPE)

Principal Investigator(s): Jurgen Sygusch, University of Montreal

Additional Investigators: None reported.

INVESTIGATION OBJECTIVES

1. To grow high-quality protein crystals in microgravity for the 15 university and industrial researchers involved with the mission.

2. To compare the resolution limits and mosaic spread between the space-grown crystals, ground-grown crystals, and space-grown crystals mounted on the Microgravity Isolation Mount (MIM).

3. To provide an opportunity for elementary and high school students to participate in a space experiment as part of an educational outreach program.

PHASE 1 MISSIONS

Mir 24/NASA 6

OPERATIONAL ACTIVITIES

Two identical sets of over 800 samples of 32 individual proteins will be grown in two separate crystallization units. The crystallization units use sliding blocks to mix protein solutions with precipitants. Certain cartridges of both sets have windows through which the growth process can be videotaped. One set of crystal growing chambers will be attached to the side of the Microgravity Isolation Mount (MIM) locker and subjected to Mir microaccelerations caused by crew movements, hardware activities and Mir operations. The second set will be located on top of the magnetic flotor of the MIM, which isolates experiments from external forces, such as microaccelerations. Data from these two sets, when compared, will show the effects of microgravity isolation on protein crystal growth.

RESULTS

MIM optical disks and CAPE video tapes are in the process of being analyzed at this time. The CAPE hardware did produce a large number of crystals, which are in the process of being analyzed by x-ray diffraction techniques.

No results have been reported to date.

CONCLUSIONS

No conclusions can be drawn at this time.

PUBLICATIONS

None.

Investigation Title: Candle Flame in Microgravity (CFM) - MGBX

Principal Investigator: Dr. Daniel L. Dietrich, NASA/Lewis Research Center

Additional Investigators: Prof. James S. T'ien and Dr. Howard D. Ross

INVESTIGATION OBJECTIVES

1. Determine if a quasi-steady candle flame can exist in a microgravity environment.
2. Determine the characteristics of the steady flame.
3. Study the previously observed pre-extinction oscillations.
4. Observe the interactions between two closely spaced candle flames.

PHASE 1 MISSIONS

NASA 2

OPERATIONAL ACTIVITIES

79 total candles burned, with three different wick diameters, two different candle diameters, and two different initial exposed wick lengths.

RESULTS

Data consisted of primarily 35 mm photographs of the flame and crew audio commentary. Results compared favorably with a recently developed numerical model of the microgravity candle flame. Both showed very long flame lifetimes are possible and the existence of pre-extinction flame oscillations. Limited number of 2 candle tests performed in favor of more single candle tests. New behavior observed -- long-lived flame oscillations and postflight aerosol cloud.

CONCLUSIONS

A steady flame is possible (at least in elevated oxygen concentrations) and pre-extinction flame oscillations are inherent to candle flames in microgravity.

PUBLICATIONS

1. Ferkul, P.V., et al. "Combustion Experiments on the Mir Space Station," AIAA 99-0439.
2. Dietrich, D.L. et al. "Candle Flames in Non-Buoyant Atmospheres," in preparation.

Investigation Title: Cartilage in Space - BTS

Principal Investigator: Lisa E. Freed, M.D., Ph.D., Massachusetts Institute of Technology (MIT)

Additional Investigators: Gordana Vunjak-Novakovic, Ph.D., Neal R. Pellis, Ph.D., and the NASA/Johnson Space Center team working on BTS

INVESTIGATION OBJECTIVES

Exposure of humans to microgravity affects cells and tissues at a variety of levels. Musculoskeletal changes (e.g. significant bone and muscle loss) occur even when astronauts exercise regularly, but the mechanisms are not yet understood. Previous flight experiments examined cells in monolayers and lasted 6-28 days. Tissue engineering, a new field enabling three-dimensional tissue equivalents to be created from isolated cells in conjunction with biomaterials and bioreactor culture vessels, can provide a basis for systematic, controlled in vitro studies. Cartilage was selected as a model musculoskeletal tissue for this first long-term space study because of its resilience and low metabolic requirements. Our working hypothesis was that in vitro cartilage formation is affected by space flight. Our specific objectives were two fold: (1) to maintain cell viability for four months in space and (2) to study effects of the space environment on the growth and function of tissue engineered cartilage.

PHASE 1 MISSIONS

NASA 3

OPERATIONAL ACTIVITIES

Preflight (MIT): Cell-polymer tissue “constructs” based on bovine calf articular chondrocytes and biodegradable polyglycolic acid scaffolds (5 million cells per 5 mm diameter x 2 mm thick scaffold) were cultured in rotating bioreactors for 3 months at 1 g prior to launch. Culture medium consisted of Dulbecco’s modified Eagle medium with 4.5 g/L glucose, 10% fetal bovine serum, 10 mM HEPES buffer, 0.1 mM nonessential amino acids, 0.4 mM proline, 50 mg/L ascorbic acid, 50 U/mL penicillin, 50 mg/mL streptomycin, and 0.5 mg/mL fungizone. After 3 months, constructs were transferred into each of two flight-qualified rotating, perfused bioreactors (the Biotechnology system, BTS) for an additional 4 months of cultivation on either the Mir Space Station or on Earth. Specifically, one BTS containing ten constructs was transferred to Mir via the US Space Shuttle STS-79 (9/16/96 launch) and brought back to Earth via STS-81 (1/22/97 landing). A second BTS with ten constructs served as an otherwise identical study conducted on Earth, at JSC.

Flight and ground control studies (astronaut John Blaha, NASA-JSC team): Medium was recirculated between the bioreactor and the gas exchanger at 4 mL/min for 20 min four times per day, and 50 to 100 mL of fresh medium were infused into the system approximately once per day. As a result, medium metabolic parameters were maintained within previously established target ranges (i.e. pH between 6.9 and 7.4, partial pressure of oxygen between 71 and 127 mmHg, and glucose concentration between 3.0 and 4.3 g/L) in both groups for the duration of the study, as assessed using portable cartridges. Concentration gradients within the bioreactor were minimized by differential rotation of the inner and outer vessel walls at 10 and 1 rpm, respectively, in microgravity, and by the convection associated with gravitational construct settling during solid body rotation of the bioreactor at 28 rpm in unit gravity. In the Mir group, gas bubbles were observed in the bioreactor between flight days 40 and 130. The amount of gas stabilized at approximately 20% of the total bioreactor volume, and the bubbles did not appear to come into direct contact with the constructs, as assessed by videography. An equal amount of gas was introduced into the bioreactor in the Earth group, in order to match conditions on Mir as closely as possible.

Postflight (MIT): Constructs were assessed at the time of launch (i.e. after 3 months of culture) and after 4 additional months on either Mir or Earth (i.e. after 7 months of culture), and compared to full thickness natural calf articular cartilage. Constructs were assessed with respect to the following parameter: (1) size and morphology (weight, histological/ultrastructural appearance); (2) biochemical composition (DNA, glycosaminoglycan (GAG), collagen type II, total collagen); (3) viability of reisolated cells (trypan blue exclusion, intracellular esterase activity); (4) tissue metabolism (incorporation of radiolabeled tracers into macromolecular GAG and collagen); (5) mechanical properties in confined compression (aggregate modulus, dynamic stiffness, hydraulic permeability).

RESULTS

Cellular viability: Mir-grown constructs assessed 30 hours postflight were comparable to Earth-grown constructs with respect to cell viability and biosynthetic activity. Specifically, constructs from both groups consisted of 95-99% viable cells, as judged by trypan blue exclusion and by intracellular esterase activity, and incorporated radiolabeled tracers into macromolecules at comparable rates. The latter may represent a rebound in chondrocyte metabolism in the Mir-grown constructs, which were assayed following return from space.

Construct shape: Constructs grown on Mir tended to become more spherical while those grown on Earth maintained their initial discoid shape, as assessed histologically and from their respective aspect ratios (i.e. height to width) of 0.72 ± 0.08 and 0.62 ± 0.03 ($p<0.05$). These findings might be related to differences in cultivation conditions, i.e. videotapes showed that constructs floated freely in microgravity but settled and collided with the rotating vessel wall at 1 g.

Construct structure: Final samples from Mir and Earth appeared histologically cartilaginous throughout their entire cross-sections (5 - 8 mm thick), with the exception of fibrous outer capsules (0.15 - 0.45 mm thick), as assessed using safranin-0 stain for GAG and immunohistochemical staining for collagen type II. Constructs grown on Earth appeared to have a more organized extracellular matrix with more uniform collagen orientation as compared to constructs grown on Mir, but the average collagen fiber diameter was similar in the two groups (22 ± 2 nm).

Construct composition: Constructs at the time of launch and after additional cultivation on Mir and on Earth contained 13 ± 1, 14 ± 0.8 and 19 ± 0.2 million cells, respectively. On Earth, construct wet weights increased 1.7-fold between 3 and 7 months, which could be attributed to increasing amounts of cartilage-specific tissue components (i.e. GAG and collagen type II). In contrast, on Mir construct wet weights increased 1.3-fold over the same time interval, due to deposition of collagen and unspecified components that were not GAG. The polymer scaffold represented less than 0.3% of the final construct wet weight. The fraction of the total collagen that was type II decreased, but not significantly, from $92\pm19\%$ at launch to $78\pm4\%$ at landing, demonstrating relatively good maintenance of the chondrocytic phenotype.

Construct function: Construct mechanical properties improved both on Mir and on Earth resulting in an increase in aggregate modulus, H_A, and a decrease in hydraulic permeability, k. Dynamic stiffness also increased with culture time and showed the characteristic frequency dependence of natural cartilage. Mechanical properties of Mir-grown constructs were inferior to those of Earth-grown constructs. Specifically, the aggregate modulus of Earth-grown constructs was indistinguishable from natural calf cartilage and was three-fold higher than that of Mir-grown constructs.

CONCLUSIONS

Tissue engineering is the creation of new tissues from component cells and biomaterial scaffolds. Our flight study was the first to demonstrate that engineered tissues can be grown for several months in space. Cartilaginous tissues grown on Mir were smaller, more spherical, and mechanically weaker than corresponding tissues grown on Earth. Our data is consistent with previous reports that space flight weakens the bones and muscles of experimental animals and humans. but ours was the first controlled comparison of isolated tissues grown on space or Earth for period of several months. Further studies of tissue engineering in space might help us understand, prevent or treat conditions such as osteoporosis that affect astronauts as well as bedridden and elderly people on Earth

PUBLICATIONS

1. Tissue Engineering of Cartilage in Space. L.E. Freed, R. Langer, I. Martin, N.R. Pellis, G. Vunjak-Novakovic. Proc. Nat. Acad. Sci. U.S.A. 94: 13885-13890, 1997. This paper can be accessed at http://www.pnas.org. A commentary on this work appeared in the same PNAS issue on page 13380.

2. Freed, L.E., Pellis, N., Searby, N., de Luis, J., Preda, C., Bordonaro, J., Vunjak-Novakovic, G. Microgravity Cultivation of Cells and Tissues. Gravitational & Space Biology Bull. (invited article, submitted 10/98)

Investigation Title: Colloidal Gelatin

Principal Investigator: Dave A. Weitz, Ph.D., University of Pennsylvania

Additional Investigators: Prof. P.N. Pusey and Dr. P.N. Segre

INVESTIGATION OBJECTIVES

Study growth of binary colloidal alloy crystals, colloid-polymer gels and fractal colloidal gels by static and dynamic light scattering. Some supplementary photography also planned. The primary goal of these experiments was to assist in optimizing sample choice for future experiments, Physics of colloids in Space, scheduled to fly in the express rack on the ISS. The glovebox experiments help mitigate the risk of the ISS experiment.

PHASE 1 MISSIONS

NASA 5

OPERATIONAL ACTIVITIES

All light scattering results were not performed due to the loss in power on Mir due to the collision. However, extensive photographs were taken, primarily of colloid-polymer mixtures, and also of binary alloy colloidal crystals.

RESULTS

Pictures of binary colloid alloys obtained; pictures of colloid-polymer mixtures obtained.

CONCLUSIONS

Unexpected structures were seen in the colloid-polymer mixtures. These structures suggest that the phase separation proceeds along different paths, that the crystals may grow out of the liquid in some instances, while out of the gas in other instances. Such results have never been observed on Earth because gravity leads to macroscopic phase separation, which obscures these results. These results have helped inspire new experiments, now planned primarily for PCS2.

PUBLICATIONS

NASA report, and several in preparation.

Investigation Title: Forced Flow Flamespread Test (FFFT)

Principal Investigator: Dr. Kurt Sacksteder, NASA/Lewis Research Center

Additional Investigators: Prof. James S. T’ien, Mr. Paul S. Greenberg, and Dr. Paul V. Ferkul

INVESTIGATION OBJECTIVES

Enhance the understanding of flame spreading over solid fuel surfaces in low-speed flows by: determining the structure of spreading flames in terms of temperature, species concentrations and velocity fields; and determining the mechanisms that induce flammability limits.

PHASE 1 MISSIONS

NASA 2

OPERATIONAL ACTIVITIES

In the Microgravity Glovebox, all samples successfully ignited and burned in very low speed airflow: Four flat cellulose samples of differing thicknesses, four samples of polyethylene wire insulation.

RESULTS

Video and film images obtained for each sample. Fuel and flame temperatures measured. Comparison of flame structure with numerical simulation of thinnest cellulose sample complete and successful. Wire insulation samples show more complete burning in orbit than in Earth-bound tests.

CONCLUSIONS

Glovebox environment useful for flame spread tests at the lowest airflow velocities.

PUBLICATIONS

1. Ferkul, P.V., et al. “Combustion Experiments on the Mir Space Station,” AIAA 37th Aerospace Sciences Meeting, AIAA-99-0439, January 1999.

Investigation Title: Interface Configuration Experiment (ICE) in the Microgravity Glovebox

Principal Investigator(s): Paul Concus, University of California at Berkeley

Additional Investigators: Robert Finn and Mark Weislogel

INVESTIGATION OBJECTIVES

The objective of this experiment is to investigate symmetry breaking for liquid surfaces in microgravity by use of specifically designed containers, and to compare observed shapes with mathematical predictions. For the containers in the experiment, the liquid is predicted mathematically to have the striking property that any stable configuration it assumes cannot be rotationally symmetric, even though the containers themselves are rotationally symmetric; furthermore it is predicted that there can be more than one such asymmetric stable configuration for a prescribed liquid volume.

PHASE 1 MISSION

Mir 21/NASA 2

OPERATIONAL ACTIVITIES

Two identical vessels, made of acrylic plastic, were flown. The test portions of the vessels were in the shape of a right circular cylinder with a mathematically determined toroidal-like bulge near the midpoint. The reservoir portions contained the test liquid, an immersion oil indexed matched with the acrylic plastic. At the initiation of each test, the liquid was transferred to the test portion of the vessel. Subsequently, perturbations were applied by the crew member to induce the liquid to assume different configurations and to test stability. The liquid behavior was recorded on video tape, along with verbal comments of the crew member.

RESULTS

The crew member (Dr. Lucid) skillfully and successfully found two distinct locally stable non-rotationally-symmetric configurations in the same container. Four static surfaces in all were formed: First the (unstable) rotationally symmetric configuration observed during the initial filling, then the apparent global minimizer like the one found numerically, then (following further carefully applied disturbances) another local minimizer that had also been found numerically. Finally, a further disturbance led once more to the minimizing surface, this time in reflected configuration.

CONCLUSIONS

It was confirmed that stable equilibrium configurations of liquid in a rotationally symmetric container with symmetric boundary data (contact angles) need not themselves be rotationally symmetric. Thus symmetry breaking in capillary configurations must be expected physically. Additionally, more than one distinct asymmetric stable configuration can occur. These results communicate clearly the need for designers of in-space fluid management systems to take account of possible unusual behavior that may not be easy to anticipate.

PUBLICATIONS

1. R. Finn, Non uniqueness and uniqueness of capillary surfaces, Manuscr. Math., 61 (1988), pp. 347-372.
2. Callahan, M., Concus, P., Finn, R., Energy Minimizing Capillary Surfaces for Exotic Containers, in Computing Optimal Geometries (with accompanying video tape), J.E. Taylor Ed., AMS Selected Lectures in Mathematics, Amer. Math. Soc., Providence, RI, 1991, pp. 13-15.
3. Concus, P., Finn, R., Exotic Containers for Capillary Surfaces, Journal of Fluid Mechanics, Vol. 224, 1991, pp. 383-394; Corrigenda, Journal of Fluid Mechanics, Vol. 232, 1991, pp. 689-690.
4. P. Concus, R. Finn, and M. Weislogel, Drop-tower experiments for capillary surfaces in an exotic container, AIAA J., Vol. 3, Jan. 1992, pp.134-137.

5. P. Concus, R. Finn, M. Weislogel; Interface Configuration Experiment: Preliminary Results, Joint Launch + One Year Science Review for USML-1 and USMP-1 with Microgravity Measurement Group, NASA CP-3272, Vol. 2, 1994, pp. 525-541.

6. P. Concus, R. Finn, and M. Weislogel, Capillary surfaces in an exotic container: results from space experiments, Report PAM737, Center for Pure and Applied Mathematics, Univ. California, Berkeley, 1998, submitted to J. Fluid Mech.

Investigation Title: Interferometric Study of Protein Crystal Growth in the Microgravity Glovebox

Principal Investigator(s): Alexander McPherson, Ph.D., University of California at Irvine

Additional Investigators: Stanley Koszelak

INVESTIGATION OBJECTIVES

1. Provide a technology demonstration and development effort of an interferometery system to study Protein Crystal Growth (PCG) in microgravity.

2. Study solute concentration gradients surrounding growing proteins crystals to obtain evidence regarding the role of growth unit aggregation in PCG.

PHASE 1 MISSIONS

NASA 6

OPERATIONAL ACTIVITIES

The IPCG hardware will be transported to Mir on STS-86. The IPCG hardware will then be installed in the Microgravity Glovebox for experiment operations. Once installed, the crew initiated experiment operations and utilized an optics system and computer software to collect optical data from the experiment. At the end of all the experiments, the IPCG hardware was removed from the glovebox and returned to stowage. The IPCG and associated hardware was returned on STS-89.

RESULTS

There were 492 images present on the IPCG computer in lieu of the expected 4,140 possible images. Power outages, possible environmental vibrations, and intermittent automatic camera digitization made the results less than desirable.

The IPCG hardware succeeded magnificently, especially with the commercial PC boards and the data acquisition and control system. Several lessons learned and minor redesigns of the fluid and optics systems should be implemented in any follow-on investigations.

CONCLUSIONS

No conclusions

PUBLICATIONS

No publications

Investigation Title: Liquid Metal Diffusion Experiment (LMD) - Microgravity Isolation Mount

Principal Investigator(s): Franz Rosenberger, University of Alabama in Huntsville

Additional Investigators: R.M. Banish

INVESTIGATION OBJECTIVES

1. Measure the diffusion coefficient of In metal at 185° C.
2. Investigate the "wall effect", i.e., transport differences between the bulk and wall regions of the sample.
3. Characterize the convective contamination of diffusivity measurements on Earth via using the MIM in its three operating modes: 3a.vibration isolation, 3b.programmed g-input and 3c.deactivated.

PHASE 1 MISSIONS

NASA 4

OPERATIONAL ACTIVITIES

The LMD apparatus was mounted to the Microgravity Isolation Mount (MIM) with four captive screws. The MIM was used to provide several different acceleration profiles to the LMD during the running of five samples on the Mir Space Station. The MIM oven is used to heat the samples up to 185 degrees Celsius and, the samples are allowed to diffuse for 96 hours. Following sample processing, data from the LMD is transferred to the MIPS system for data storage.

RESULTS

The raw LMD data from the three completed diffusion runs have been processed. Diffusivity values have been obtained. Accelerometer data from the MIM has been received and reviewed. The diffusivity values obtained from experiments conducted on Mir/NASA 4 are within 5% (i.e., within the experimental error) of the terrestrial experiments. No effect of the container wall on diffusive transport was detected. The acceleration disturbances measured on the MIM floater platform (during sample processing) were generally less than 10^{-4} g for the latched (deactivated) mode and 10^{-6} g for the isolating mode. Thus, buoyancy-driven convection effects were minimal in our samples.

CONCLUSIONS

Similarities between the self-diffusivity of Indium at 185°C between the terrestrial and space experiments was observed. At 185°C the temperature non-uniformities in the liquid indium were probably less than 0.05°C. The residual acceleration/g-jitter was typically less than 10^{-4} g. Therefore, convective contamination was minimal. In addition, the scatter of all diffusivity values were well within the experimental error; which is not true for the ground-based measurements. The performance of our radiation detectors and our sample containment method was well within our expectations. Hence, these components will be used for future missions. Although increased background noise from the South Atlantic Anomaly was evident in the detector data, it did not interfere with the diffusivity measurements. These results will be published shortly.

PUBLICATIONS

No publications

Investigation Title: Mechanics of Granular Materials (MGM)

Principal Investigator: Stein Sture, Ph.D., University of Colorado at Boulder

Additional Investigators: Dr. Nicholas C. Costes, Dr. Khalid AlShibli, Dr. Roy A. Swanson, Mr. Mark Lankton, Ms. Susan Batiste, Mr. Tae-Hyung Kim, and Ms. Maria P. Tchonkova

INVESTIGATION OBJECTIVES

Not provide by PI.

PHASE 1 MISSION

STS-79, STS-89

OPERATIONAL ACTIVITIES, ETC.:

Since the time-fuse is very short, let me again refer to the web-site, which might help answer most of these:

http://bechtel.colorado.edu/~batiste/

RESULTS

A set of nine very low effective confining stress level experiments, wre conducted in the microgravity environment of the Space Shuttle (STS-79, September, 1996 and STS-89, January, 1998). Conventional triaxial one-way cyclic compression and compression-extension cyclic (small and large amplitude) experiments were conducted on medium dense cylindrical specimens measuring 75 mm diameter by 150 mm long on dry quartz sand under displacement rates of 35 mm/hr, to total axial strains of 25% at confining stresses in the range of 0.05 - 1.30 kPa. In the absence of cohesion, the friction angles observed were in the range of 75 (+/- 1) to 70 (+/- 1) degrees at the lowest confining stress level to 56 degrees at the higest level. The dilatancy angles for all experiments were in the range of 30 degrees. The deformations were relatively uniform in all cases right up to the maximum displacements. No shear bands or other forms of localized deformation were visible at the surfaces of the specimens. The overall behavior of the specimens was brittle-ductile with significant material instabilities only at the 0.05 kPa level, resulting in strain-softening. More ductile behavior was seen at the 0.52 and 1.30 kPa levels. X-ray computed tomography studies show relatively uniform internal structure with radial-turbine screw fan-like patters appearing almost periodically, where the fans constitute zones of dilation. The specimens'overall nominal stress-strain response curves display periodic patterns of minor instability, with stress variations resembling stick-slips that were of a magnitude 5-10% of the overall stress levels. These periodic material instabilities appear to be independent of confining stresses in the ranges that were studied. All six experiments showed significant initial stiffnesses, which were comparable to the regularly spaced observed unloading-reloading stiffness responses. It appears that there is little or no coupling between the unloading-reloding stiffness modulus behavior, which is predominantly elastic, and the confining stress level, or the amount of inelastic deformations induced. Ground-based experiments were compared to the flight data, and it was shown that the in-space experiments showed consistently higher fricton and dilatancy angles at the lower confining stresses. Analysis of the flight experiments and the terrestrial tests show that there is internal consistency in the material properties except for the very high dilatancy and friction angles, and elastic moduli seen in the microgravity experiments. These findings have large impact on engineering and science involving the mechanics of granular materials, such as Earthquake engineering, geotechnical engineering, coastal and ocean engineering, sediment transport, geophysics, storage and handling of bulk (granular) solids, etc.

CONCLUSIONS

Not Provided by PI.

PUBLICATIONS

Journal Articles

1. Runesson, K., Larsson, R., and Sture, S. Localization in hyperelastic-plastic porous solids subjected to undrained conditions, Int. J. Solids and Structures, Pergamon Press, Vol. 35, No. 31-32, pp. 4239-4255, 1998.
2. Sture, S., Costes, N.C., Batiste, S.N., Lankton, M.R., Alshibli, K.A., Jeremic, B., Swanson, R.A., and Frank, M., Mechanics of granular materials at low effective stresses, ASCE, J. of Aerospace Engineering, Vol. 11, No. 2, July, pp. 67-72, 1998.
3. Jeremic, B., and Sture, S., Tensor objects in finite element programming, Int. J. Numerical Methods in Engineering, Vol. 41, 113-126, 1998.

Proceedings

4. Jeremic, B., Runesson, K., and Sture, S., Large deformation elasto-plastic analysis of geomaterials: from experiment to numerical predictions, Proc. Int. Conf. on Comp. Meth. and Advances in Geomech., Wuhan, PR China, November, 1997, Vol. 2, 678-692.
5. Alshibli, K.A., Swanson, R.A., Costes, N.C., Sture, S., Batiste, S.N., and Lankton, M.R., Mechanics of granular materials under very low effective stresses in a microgravity environment, Proc. Am. Geophysical Union, Boston, Massachusetts, April, T21B-8, 1998.
6. Swanson, R.A., Alshibli, K.A., Frank, M., Costes, N.C., Sture, S., Batiste, S.N., Lankton, M.R., and Jeremic, B., Mechanics of granular materials in microgravity at low effective stresses, Proc. Am. Geophysical Union, Boston, Masaachusetts, April, T21B-7, 1998.
7. Alshibli, K.A., Sture, S., and Costes, N.C., Effect of inclusions on plane strain behavior of sand, ASCE, Proc. 12th Engineering Mechanics Conference, Univ. of California, San Diego, May, CD-ROM, 1998.
8. Costes, N.C., and Sture, S., A mobility concept for Martian exploration, Proc. ASCE, 5th Int. Conference on Engineering, Construction and Operations in Space, Vol. 1, 489-494, 1998.
9. Jeremic, B., Runesson, K., and Sture, S., Finite deformation hyperelasto-plasticity of geomaterials: Numerical integration algorithms, Proc. 13th U.S. Natl. Congress of Applied Mechanics, Univ. of Florida, MA9, June, 1998.
10. Sture, S., Modeling of granular materials at low stresses, Proc. 13th U.S. Natl. Congress of Applied Mechanics, Univ. of Florida, MB9, June, 1998.
11. Sture, S., and Costes, N.C., Mechanics of granular materials at very low effective stresses, Proc. 13th U.S. National Congress of Applied Mechanics, University of Florida, gainesville, MB9, June, 1998.

Presentations

12. Sture, S., "Experiments and Analysis of Granular Materials aboard the Space Shuttle", Invited Lecture, Colorado School of Mines, Department of Engineering, Golden, Colorado, March 31, 1998.
13. Sture, S., "Mechanics of Granular Materials under Low Effective Stresses and Static Conditions", Invited Lecture, Cornell University, Department of Theoretical and Applied Mechanics, April 15, 1998.
14. Sture, S., "Microgravity and Low Stress Experiments on Granular Materials aboard the Space Shuttle," Moran Lecture in Engineering, University of Notre Dame, Indiana, April 30, 1998.
15. Sture, S., "Mechanics of Granular Materials at Low Effective Stresses", Fourth Microgravity Fluid Physics and Transport Phenomena Conference, Cleveland, Ohio, August 14, 1998.
16. Sture, S., "Constitutive Issues in Soil Liquefaction, Int. Workshop on the Physics and Mechanics of Soil Liquefaction", NSF and Johns Hopkins University, Baltimore, Maryland, September 10, 1998.

(Lectures and proceedings papers related to NASA/JSC organized symposia in connection with 180-day results reports, 360-day reports, and NASA microgravity results symposia (organized by John Uri et al., at JSC, and

held at NASA Ames Research Center, April 1-3, 1998, etc. are not included. It is assumed that these have found their way into your database separately.)

17. Batiste, S.N., Lankton, M.R., and Sture, S., "Mechanics of Granular Materials: STS-89/Mir8 experiments," Second Phase 1 Research Program Results Symposium, NASA, Ames Research Center, April 1, 1998.

Report

18. Sture, S., Costes, N.C., Batiste, S.N. Lankton, M.R., Alshibli, K.A., and Swanson, R., 180-day Report: Mechanics of Granular Materials Experiment Research Results, Report to NASA, Johnson Space Center, June, 1998.

Investigation Title: Microgravity Glovebox (MGBX) Facility Operations

Principal Investigator(s): Don Reiss, Ph.D., NASA/Marshall Space Flight Center

Additional Investigators:

INVESTIGATION OBJECTIVES

1. To provide a level of containment by providing a physical barrier between the MGBX working area and the ambient environment.
2. To maintain a negative pressure within the working area during normal operations.
3. To provide a working area in which to perform experiments with a window for viewing the experiments.
4. To store data on orbit to support experiment correlation with environmental status during operation of the experiments.

PHASE 1 MISSIONS

NASA 2 - NASA 6

OPERATIONAL ACTIVITIES

The glovebox facility was used on NASA 2, 3, 4, 5, and 6 to support multiple Microgravity science experiments. The glovebox facility was brought back to the ground on STS-89.

RESULTS

NASA 2 - The experience gained on NASA 2 has been very valuable. The facility met all expectations. A total of 100 operational hours were accumulated.

NASA 4 - The NASA 4 investigation data has been reduced and supplied to the respective MGBx-housed investigative teams. The MGBx facility operated flawlessly during the 290 hours of accumulated time through NASA 4.

NASA 5 - The Mir GBX facility operated flawlessly during the 461 hours of accumulated time through NASA 5.

NASA 6 - NASA 6 was the final mission scheduled for Mir MGBx science operations. At the conclusion of this mission, the MGBx was cleaned and all experiment and facility hardware was stowed for return on STS-89. On return to MSFC, the facility was inspected and found to be in generally good condition, and was cleaner than originally expected due to the efforts of the crew. The expected amount of wear was evident, and some refurbishment would be required to prepare the facility for reflight.

CONCLUSIONS

The Mir Glovebox (MGBX) for Microgravity Investigations was located in the Priroda module of the Mir Space Station. The glovebox provided work area for microgravity investigations that can be physically isolated from the crew environment. The air filtration system provided a negative pressure in the work area with respect to crew environment. Two separate banks of filters contained solid and liquid materials, preventing contamination of the crew environment.

PUBLICATIONS

No publications

Investigation Title: Microgravity Isolation Mount (MIM)

Principal Investigator(s): Bjarni Tryggvason, Ph.D., Canadian Space Agency (CSA)

Additional Investigators:

INVESTIGATION OBJECTIVES

1. Ensure that the Microgravity Isolation Mount (MIM) provides an isolated microgravity condition (free from acceleration disturbances) for conducting experiments.

PHASE 1 MISSIONS

NASA 2 - NASA 7

OPERATIONAL ACTIVITIES

NASA 2 - The MIM was operated in support of three experiments during NASA 2 on the Mir Space Station: (1) MIM Performance Verification Experiments (2) QUELD II Experiments and (3) The TEM experiment. NASA 3 - The MIM was operated in support of one experiment during NASA 3 on the Mir Space Station: (1) The MIM Performance Verification Experiment. NASA 4 - The MIM was operated in support of two experiments during the NASA 4 mission on Mir Space Station: (1) The Liquid Metal Diffusion Experiment and the (2) QUELD II experiment.

RESULTS

NASA 2 - MIM data was copied to optical disks. These disks were returned to Earth on STS-79. The MIM and TEM experiments used their own optical disks. The QUELD experiment used optical disks supplied by the MIPS-2C. The MIM and TEM optical disks were returned to their respective PIs. The MIPS optical disks were returned to JSC. Copies of the data on the MIPS optical disks were made by NASA onto CD-ROMs and supplied to the CSA. Working copies of the data from the MIM and TEM disks were made to CD-ROMs at the Canadian Space Agency. For the TEM experiment three such copies have been made with one being returned to the TEM PI. The original flight optical disks for both the MIM and TEM have been placed in storage for future uses. At 30 days postflight, a summary of MIM runs, a summary of event files, a summary of experiment runs, optical disk and CD-ROM Listing, and a summary of analysis results has been prepared.

NASA 3 - Data analysis is ongoing. MIPS provided optical disks were used to archived the MIM data. These disks were returned to Earth on STS-81. The MIPS optical disks were returned to JSC. Copies of the data on the MIPS optical disks were made by NASA onto CD-ROMS and supplied to CSA, on March 14,1997. At 30 days postflight, a summary of MIM runs, a summary of event files, a summary of experiment runs, optical disk and CD-ROM Listing, and a summary of analysis results has been prepared.

NASA 4 - The MIM facility was used to support LMD and the QUELD experiment.

CONCLUSIONS

NASA 2 - There were 63 QUELD runs. This compares to the 32 planned. Additional runs were required to operate the QUELD unit with only one of its two furnaces operating. There were 18 TEM runs compared to the 10 planned. Again extra runs were required in an attempt to recover data that was not stored properly.

NASA 4 - The MIM facility has accumulated more than 1200 hours of operations without any mechanical or electrical malfunctions. During the conduct of the LMD experiment operational difficulties have been encountered, an example is the discrepancy between estimated versus actual time to perform various tasks. The content of the MIM event files will be used to determine the reasons for the discrepancy and corrective measures will be implemented in future missions. Overall the MIM performed as planned and was capable of providing improved microgravity conditions over long periods of time, up to 96 continuous hours without interruption.

PUBLICATIONS

No publications available

Investigation Title: Opposed Flow Flame Spreading over Cylindrical Surfaces (OFFS)

Principal Investigator: Robert A. Altenkirch, Mississippi State University

Additional Investiators: Dr. Kurt Sacksteder, Prof. Subratta Bhattacharjee, and Dr. Michael A. Delichatsios

INVESTIGATION OBJECTIVES

Enhance the understanding of flame spreading over solid fuel surfaces in the presence of low-speed opposed flows; especially considering effects of radiation heat transfer from cylindrical fuels. Seek flammability limit in terms of air velocity for cylindrical samples.

PHASE 1 MISSIONS

NASA 4

OPERATIONAL ACTIVITIES

In the Microgravity Glovebox, four of eight samples successfully ignited and burned. Remaining samples judged to be not flammable under the test conditions.

RESULTS

Video and film images obtained for four samples. Change in flame spread characteristics observed with change in air flow velocity. Observed flammability limit for thick cylindrical sample.

CONCLUSIONS

Glovebox environment useful for flame spread tests at the lowest airflow velocities. Differences between flame spread characteristics for flat and cylindrical samples attributed to differences in radiative heat losses.

PUBLICATIONS

1. Ferkul, P.V., et al. “Combustion Experiments on the Mir Space Station,” AIAA 37th Aerospace Sciences Meeting, AIAA-99-0439, January 1999.

Investigation Title: Passive Accelerometer System (PAS) - MGBX

Principal Investigator: J. Iwan D. Alexander, Case Western Reserve University

INVESTIGATION OBJECTIVES

The objective of the passive accelerometer system (PAS) is to measure, at various locations in the spacecraft, the small (10^{-6} μg) quasi-steady residual acceleration caused by a combination of atmospheric drag effects and the gravity gradient.

PHASE 1 MISSIONS

Mir 22/NASA 3

OPERATIONAL ACTIVITIES

PAS was deployed on 10 separate occasions between October 20 and December 17, 1996. The acceleration measurement is obtained by recording the motion of a spherical proof mass along an oriented liquid-filled tube. Modified Stokes' Law uses trajectory and speed to calculate acceleration.

RESULTS

Successful operation. Measured accelerations up to 1.9 μg and as low as 5×10^{-2} μg. High and low accelerations measured at the same location but at different times.

CONCLUSIONS

Higher acceleration values consistent with orbital attitude and estimated atmospheric drag. Lower values suprising. Explanation: simulations show that proximity to CG + quasi-inertial attitude can lead to periods of practically no proof mass motion when the drag accelerations are low enough ($\Rightarrow$ low average acceleration)

PUBLICATIONS

1. J. Iwan D. Alexander and M.J. B. Rogers, Passive Accelerometer Measurements on Mir and STS-50, to be submitted to Microgravity Science and Technology, 1999.

Investigation Title: Protein Crystal Growth (PCG) GN2 Dewar

Principal Investigator: Alexander McPherson, Ph.D., University of California at Irvine

Additional Investigator: Stan Koszelak, Ph.D.

INVESTIGATION OBJECTIVES

1. Crystallize proteins, nucleic acids, viruses, and polypeptides in a microgravity environment taking advantage of the long duration afforded by Mir.
2. Crystallize a very large number of samples inexpensively, simply, with minimal flight resources.
3. Identify for most investigations the likelihood that microgravity will be a useful variable.
4. Provide a method for the optimization of crystallization conditions for particular sample types.
5. Improve the diffraction quality of macromolecule crystals for X-ray study on Earth.
6. Provide a system for the exploration and definition of ideal microgravity experiment configurations.

PHASE 1 MISSIONS

STS-71, STS-74, STS-76, STS-79, STS-81, STS-84, STS-89

OPERATIONAL ACTIVITIES:

PCG/GN2 Dewar Flight History

Flight, date	# of samples	# of proteins
STS-71 (6-27-95)	183	19
STS-74 (11-5-95)	166	16
STS-76 (3-22-96)	275	20 (2 units flown)
STS-79 (9-16-96)	285	11
STS-81 (1-12-97)	220	8
STS-84 (5-15-97)	107	11
STS-89 (1-22-98)	150	16

RESULTS

- Approximately 80% success in terms of obtaining crystals of different macromolecule samples.
- Significant size and/or X-ray quality enhancement for approximately 15% of macromolecules flown.

CONCLUSIONS

- The Liquid-Liquid Diffusion and Batch Techniques for PCG are well suited to long-duration missions remaining stable for months.
- A very large number or volume of experiments can be performed with minimal hardware or on-orbit resources.

PUBLICATIONS

1. Koszelak, S., Leja, C. and McPherson, A. Crystallization of biological macromolecules from flash frozen samples on the Russian Space Station Mir. Biotechnology and Bioengineering 52, 449-458 (1996).
2. McPherson, A. Macromolecular crystal growth in microgravity. Crystallography Reviews, 6(2) 157-308 (1996).
3. McPherson, A. Recent Advances in the Microgravity Crystallization of Biological Macromolecules. Trends in Biotechnology TIBTECH. 15 No. 6(161), pp. 197-237 (1997).

Investigation Title: Queen's University Experiment in Liquid Diffusion (QUELD)

Principal Investigator(s): Reginald Smith, Queen's University, Kingston, Canada

Additional Investigators: Kedar Tandon, University of Manitoba, Winnipeg, Canada; Robert Redden, Amistar R&D Inc, Victoria, Canada

INVESTIGATION OBJECTIVES

1. To measure the diffusion coefficients in metallic binary systems under conditions of microgravity.
2. To provide further data and increase the understanding of the diffusion problem and of the experimental data.

PHASE 1 MISSIONS

NASA 2, NASA 4, NASA 7

OPERATIONAL ACTIVITIES

NASA 2 - The QUELD was upmassed on STS-76 on May 27, 1996 and operated during the NASA 2 mission. During the period from June 10, 1996 to August 27, 1996, crewmember Shannon Lucid processed a total of 50 samples of the 55 samples planned for this mission. All the samples were returned on STS-79 in September, 1996. NASA 4 - The QUELD FA-1 was upmassed on STS-81 in January, 1997 and operated during NASA 4. During the period from March 21 to May 4, 1997, crewmember Jerry Linenger processed or attempted to process a total of 102 samples, 36 samples more than planned for NASA 4. Of these 102 samples, only 6 samples seem to have been affected by anomalies. All 102 samples were returned on STS-84 in May, 1997.

RESULTS

To date, 51 of the 55 samples have been evaluated. Of these 51 runs, 17 can be considered operational successes, the rest were affected by anomalies. The remaining 4 experiment runs are currently being evaluated. The Principal Investigators (PIs) have begun the analysis of their respective samples. Since their return from Mir, the samples have been visually inspected and re-tested for containment by vacuum test and X-ray inspection, as they were for flight qualification. This post-mission examination proved the complete integrity of the sample containment. The samples were then returned to the respective PIs. The time, temperature and acceleration data for each experiment was downloaded from the MIM optical disks. Due to the large volume of data generated by the experiments, the activity of computing and reporting the data is not yet complete - the data for 12 runs remain to be reduced. Some general results are:

- As desired, none of the samples were found to have internal shrinkage cavities.
- As desired, the X-ray inspection showed that during processing, the surface of the molten specimens had wetted the walls of the inner sheath, an indication that Marangoni convection was minimized.
- The preliminary examination of the oxide interference tints on the sample surfaces and a visual inspection of the specimen materials indicate that the experiments were highly reproducible (consistent).

NASA 4 - Samples have been visually inspected. This post-mission examination revealed that some of the samples had some external oxidation but that the integrity of the sample containment was maintained The samples and the QUELD furnace temperatures at the midpoint of the processing sequence, as obtained from data collected by the memory modules, were returned to the respective Principal Investigators (PIs).

During NASA 4, the crew processed or attempted to process 102 QUELD samples, 36 more samples than planned. Of these 102 samples, 6 samples have been affected by operating anomalies. Five of these samples were not processed or partially processed because the QUELD thermal switch interrupted the sequence when it sensed that the safe touch temperature of the furnace module (50 C) was exceeded on the surface of the QUELD unit. One sample, sample 214, was returned, apparently without having been processed. No record of this experiment exists on the QUELD memory modules. The samples have been visually inspected by the CSA and found to have maintained containment integrity in spite of surface oxidation on some of the sample casings. The samples along with the temperature data stored on the QUELD memory modules were returned to the respective PIs. More in-depth analysis will occur once the QUELD data disks, on which the bulk of the mission data are stored, are returned to the CSA.

NASA 7 - The data disks containing data from MIM has been received and analyzed. A report was written on MIM Flight Data analysis for Queen’s (CSA-MSP-MIM-QUELD/NASA7-001) and for University of Toronto (CSA-MSP-MIM-QUELD/NASA7-002). The report will be sent to Queen’s along with the raw electronic data. The samples have not been yet analyzed by the PI. For University of Toronto, the samples as well as the report will be released when the PI will present a new proposal that would take into account the contamination factor **.** For the QUELd Furnace data, the analysis will start on reception of the Memory Modules in late August.

During NASA 7, the crew processed or attempted to process 50 QUELD samples. The 38 samples from Queen’s have been visually inspected by the PI and CSA and 4 samples seems to have not been processed. The 12 samples from University of Toronto will not be further analyzed until a new proposal is submitted. All samples have maintained containment integrity in spite of surface oxidation on some of the sample casings. All MIM data have been analysed and a report for each PI has been written including all analysed data plots. The Queen’s report will be sent to the PI along with the raw electronic data. More in-depth analysis will occur once the QUELD Memory Modules are returned to CSA.

CONCLUSIONS

No conclusions

PUBLICATIONS

No publications

Investigation Title: Space Acceleration Measurement System (SAMS) Operations

Principal Investigator: Richard Delombard, NASA/Lewis Research Center

INVESTIGATION OBJECTIVES

1. Measure the microgravity acceleration environment on Mir in support of US and Russian Phase 1 investigations.
2. Characterize the microgravity environment and pass knowledge to Principal Investigators.

PHASE 1 MISSIONS

SAMS launched to Mir on Progress vehicle in August 1994 (before N. Thaggard).

Intermittent operation as requried until return on STS-91 in June 1998 (with A. Thomas).

OPERATIONAL ACTIVITIES

- Measure accelerations near science experiments during their operations.
- Measure accelerations in support of Mir Structural Dynamics Experiment (MiSDE).

RESULTS

SAMS acquired over 50 gigabytes of data which represents 3,500 hours of operations.

CONCLUSIONS

- Mir microgravity acceleration levels generally similar to Shuttle.
- Different equipment give different characteristics.
- Major features: vehicle dockings, crew exercise, gyrodynes, Mir flight attitude, Mir susbystem equipment, crew daily cycle.

PUBLICATIONS

Seven NASA Technical Memorandum reports.

One COSPAR paper and presentation.

Investigation Title: Technological Evaluation of the Microgravity Isolation Mount (TEM-1 & 2)

Principal Investigator: Jeff Allen, National Center for Microgravity Research

INVESTIGATION OBJECTIVES

1. Demonstrate the effect of g-jitter on low-gravity fluid physics experiments.

2. Demonstrate utility of Canadian provided Microgravity Isolation Mount (MIM) to isolate fluids experiments from g-jitter and evaluate the controlled displacement capabilities of the MIM.

3. Gather new information on the damping characteristics of liquid surfaces in low-gravity.

The second Technological Evaluation of the MIM, or TEM-2, was designed to evaluate the capabilities of the MIM in a different parameter range than that of TEM-1.

PHASE 1 MISSIONS

TEM-1 experiment was launched on Priroda in April, 1996; conducted by Astronaut Shannon Lucid during the NASA 2 mission; and returned on STS-79 in September, 1996. TEM-2 experiment was launched on STS-79 in September, 1996; remained on Mir through the NASA 6 mission, but was never conducted; and returned on STS-89 in January, 1998.

OPERATIONAL ACTIVITIES

The TEM experiment required the crewmember to setup the MIM and MGBX facilities and to install the TEM experiment on the MIM. Installation included securing a TEM test cell to the MIM flotor and transferring the test fluid from the reservoir to the cylindrical test chamber. Then the TEM specific configuration files were loaded into the MIM processor and the experiment began. These files instructed the MIM to oscillate sinusoidally at a fixed frequency, amplitude, and direction for a short period of time and then return to the vibration isolation mode. This sequence of oscillation/isolation was conducted over a wide range of frequencies and acceleration levels automatically. The crewmember was not required again until the end of a complete set of imposed oscillations. At the end of the sequence, the crewmember would transfer the MIM data to an optical disk for storage. Then, a new set of configuration files would be loaded into the MIM processor and another sequence of imposed oscillations performed.

RESULTS

During the NASA 2 mission, 6 sequences of imposed oscillations were performed on each of the TEM-1 test cells. Unfortunately, all of the acceleration data for one of the test cells was lost due to an error in translating and back-translating the TEM-1 experiment procedures. The experiment was rerun on this test cell, but the fluid in the test cell had become broken into many surfaces and drops. Therefore, for this test cell, there exists video data of the liquid surface during one run and acceleration data during another run. Correlation between the two runs is ongoing.

The video data of the two test cells indicates that the dissipation of energy, or damping, is greater by an order of magnitude in the low contact angle system (wetting) than in the high contact angle system (less wetting). In addition, the natural frequency of the low contact angle system was less than that of the high contact angle system.

CONCLUSIONS

The TEM-1 experiment was a simple concept, but was greatly complicated by using three separate facilities for conducting the experiment. The MIM, the MGBX for video recording, and a third facility, MIPS, used for storing the MIM acceleration data on optical disk. The complexities of simultaneous development of facilities and experiments led to undefined interfaces between them. These complications were exacerbated by the translation of the procedures into Russian and then back into English. The crewmember, Shannon Lucid, went to great lengths to sort out the confusion, but errors and last minute changes in the crew procedures resulted in a loss of data. These errors and mistakes may have been overcome but for the lack of real-time communication between investigators and the crew on Mir.

PUBLICATIONS

1. Jeffrey S. Allen and Suzanne Saavedra, "NASA Sponsered Fluid Physics Experiments Conducted on the Mir Space Station", paper no. AIAA 99-0437, presented at the AIAA 37th Aerospace Sciences Meeting and Exhibit, January 11-14, 1999, Reno, Nevada.

Intent is to publish TEM-1 data and results in a NASA Technical Memorandum once the acceleration data is analyzed in Canada and the video is correlated.

Investigation Title: Mir Sample Return Experiment (MSRE)

Principal Investigator(s): Peter Tsou, Ph.D., Jet Propulsion Laboratoy

Additional Investigator(s): Not provided by PI

INVESTIGATION OBJECTIVES

The objective of the MSRE experiment was to collect intact cosmic dust for chemical, isotopic, organic analysis.

PHASE 1 MISSIONS

STS-76, NASA 2 - NASA 5, STS-86

OPERATIONAL ACTIVITIES

The MSRE experiment was delivered to the Mir Space Station during the launch of the Priroda Module from Baikonur Kazakstan. During an EVA by the Mir 21 crew, the experiment was attached to the exterior of the KVANT-2 Module. PIE remained outside the Mir station, requiring no crewtime during the NASA 2 and NASA 3 missions. During the NASA 4 mission, an EVA was conducted by NASA Astronaut Dr. Jerry Linenger to retrieve the experiment. The experiment was returned for study aboard the STS-84 Space Shuttle mission.

RESULTS

Besides the preliminary examination, which revealed that the longer duration exposure showed higher concentration of particles captured and an alarming number of very small particles observed, MSRE will not be analyzed until early 1999 after STARDUST is launched due to PI involvement with that mission.

CONCLUSIONS

Not provided by PI

PUBLICATIONS

Not provided by PI

Investigation Title: Particle Impact Experiment (PIE)

Principal Investigator(s): Carl R. Maag, Ph.D., T&M Engineering

Additional Investigator(s): S. P. Deshpande

INVESTIGATION OBJECTIVES

The PIE investigation had three main objectives and three tertiary objectives. The main objectives were: to capture micron/submicron dust grains in a manner that insures minimal particle degradation, to return the captured particles to Earth for complete, detailed analysis to determine the grain composition, and to identify the particle remnants of any micron sized extraterrestrial grains to be related with the possible cometary origin of the grains. The tertiary objectives included: the assessment of the level of contamination seen on the returned hardware, to study the effects of UV-radiation on organic molecules in space, and to assess hard radiation environment levels, constituents and effects.

PHASE 1 MISSIONS

NASA 2 - NASA 4, STS-84

OPERATIONAL ACTIVITIES

The PIE experiment was delivered to the Mir Space Station during the launch of the Priroda Module from Baikonur Kazakstan. During an EVA by the Mir 21 crew, the experiment was attached to the exterior of the KVANT-2 Module. PIE remained outside the Mir station, requiring no crewtime during the NASA 2 and NASA 3 missions. During the NASA 4 mission, an EVA was conducted by NASA Astronaut Dr. Jerry Linenger to retrieve the experiment. The experiment was returned for study aboard the STS-84 Space Shuttle mission.

RESULTS

Data analysis is still ongoing. However, a total of 77 impacts have been observed.

CONCLUSIONS

After 327 days on the Mir station, the following preliminary conclusions can be drawn:

- A flux-mass distribution of impacting particles has been derived with reasonable accuracy due to the large time-area exposure. Several intact captured particles have been located and removed.
- The impact data observed at the larger sizes is well above the predicted values: This suggest one of several things:
    1. The population density of larger sized particles is greater than believed at these higher altitudes (and by inference, those immediately above them); and/or
    2. The growth rate at the larger sizes is equivalent or greater that that for the smaller sized particles.
- Silicon contamination (as SiOx) was observed on the returned hardware. This has also been observed previously on other hardware returned from Mir.

PUBLICATIONS

Not provided by PI