Life into Space

Space Life Sciences Experiments
NASA Ames Research Center
1965-1990

Edited by Kenneth Souza, Robert Hogan, Rodney Ballard

Life into Space PDF Edition

About the PDF Edition

Life into Space, 1965-1990, published in 1995, and *Life into Space, 1991-1998,* published in 2000, present an overview of space life sciences missions, payloads, and experiments developed and/or managed by the NASA Ames Research Center and Kennedy Space Center. In order to extend access to this information, the original print publications have been adapted for electronic distribution. These PDF versions allow for printing any or all of the books as they appeared in the published hard copy form.

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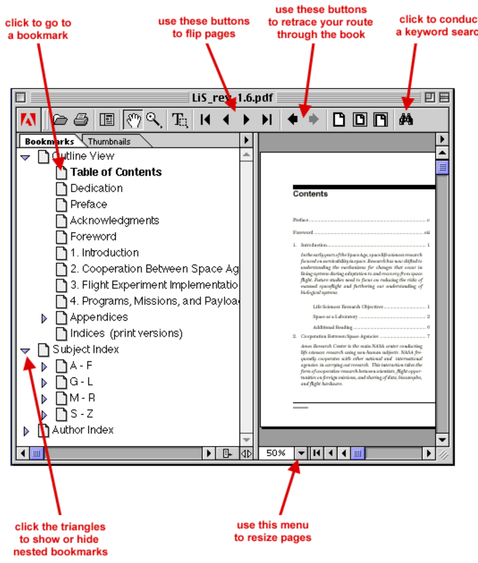

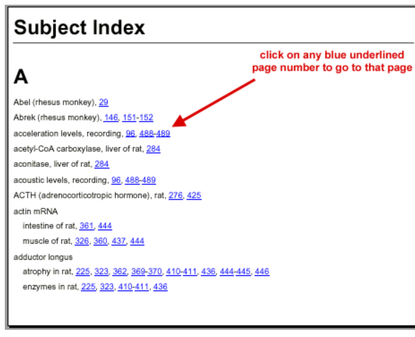

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Life Into Space 1965-1990

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Life Into Space 1991-1998

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This version has been reorganized to take full advantage of hypertext navigation.

For More Information

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DEDICATION

Life into Space is dedicated to Rodney Ballard, the former Assistant Chief of the Space Life Sciences Payloads Office at Ames Research Center and coeditor of this book, who died in August 1993. This book would not have been started without his conviction that these space life sciences accomplishments should be made readily available to the current and upcoming generation of scientists and engineers. He believed strongly in the benefits of international scientific cooperation, and was very pleased to have had a key role in some of the processes described herein. The interviews with several participants in these endeavors, included in this book, were done primarily at his urging. He thought it important for the reader to have a glimpse of some of the people and extraordinary challenges associated with conduct of this research. All those who were fortunate enough to know him will greatly miss the international vision, steadfastness, goodwill and unabashed optimism he brought to his endeavors on behalf of the Space Life Sciences Payloads Office.

A quote from a recent essay captures much of Ballard's legacy to his colleagues at home and abroad:

> In a chaotic world, friendship is the most elegant, the most lasting way to be useful. We are, each of us, a living testament to our friends' compassion and tolerance, humor and wisdom, patience and grit. Friendship, not technology, is the only thing capable of showing us the enormity of the world.

(Steven Dietz, notes from the director for the play "Jody's Maps," January 1994.)

PREFACE

Ames Research Center (ARC), along with other NASA centers, supports life sciences research in space using various living systems. Among the centers, it is the only one with the comprehensive facilities and expertise required to develop complex animal experiments. ARC began developing space life sciences experiments in the early 1960s and continues to actively support NASA's life sciences research program.

This book is the first compilation of the results of ARC's space life sciences research in a single volume. It profiles the background, objectives, and methods for this research. There have been major changes within NASA and ARC during the past 25 years, and in the way this research is managed and conducted. There has been an evolution from mission to mission toward internationalization at all levels. The core of the book describes individual missions from Gemini 3 in 1965 to STS-41 in 1990. The year 1990 was chosen as the cutoff date because the results of missions completed after this point had not yet been fully analyzed. The book provides top-level overviews of mission objectives, payload and experiment development, operations before, during, and after flight, and brief descriptions of mission results.

One-page summaries of over 200 completed experiments and the associated hardware items are provided in two major appendices. Publications for each experiment are listed in another appendix. This information should be useful to three major groups: first, NASA and contractor personnel who are responsible for experiment and payload development; second, current and prospective space life sciences investigators in universities, NASA centers, industry, and the international space life sciences community; third, members of the life sciences community that provide counsel on the content, structure and future direction of NASA's life sciences program. We asked NASA investigators to review their experiment results and associated publications so that our descriptions are as accurate as possible. We also invited input from other selected reviewers.

This book describes accomplishments by many scientists, engineers and managers at ARC, the large university science community that supports NASA life sciences research objectives, our many international colleagues, and our aerospace industry hardware development and support contractors. We are grateful for their contributions. We appreciate all the people who produced the facilities, equipment, experiments, and scientific results described in this book and are proud to have been part of this effort.

Kenneth Souza, Chief
Robert Hogan, Deputy Chief
Rodney Ballard, Assistant Chief (deceased)
Space Life Sciences Payloads Office
Ames Research Center, 1995

ACKNOWLEDGMENTS

The editors are indebted to a large group of people for their contributions to this volume. William Berry, Oleg Gazenko, Eugene Ilyin, Harold Klein, Claude Milhaud, Nello Pace, Joseph Saunders, Lyuba Serova, Joseph Sharp, Richard Simmonds, and David Winter gave insightful accounts of their involvement in space life sciences research. Several NASA staff reviewed the volume and provided valuable criticisms and suggestions, especially Paul Callahan, Bonnie Dalton, James Connolly, Michael Skidmore, Emily Holton, Charles Winget, and John Dyer. Eugene Benton and Charles Fuller also provided many helpful corrections and comments. Without the help of John Tremor, Robert Mah, Paul Dolkas, and Gary Thorley, it would have been difficult for us to collect information on several older missions. We are grateful to the more than fifty reviewers who corrected and commented on the information in this book. The staff of Spaceline (Ron Dutcher and Kathy Scott) deserve acknowledgment for their generous and substantial assistance in providing and verifying citations for this book. Also, the assistance of the Ames Research Center Life Sciences Library staff was instrumental in obtaining hard-to-find material. Bertie Cox and Lorraine Tanner (both formerly of ARC Publications Branch) gave critical support for concept development of the book and Bethann Dennis of Scientific and Commercial Systems Corporation provided invaluable editorial support.

We would especially like to thank the staff of Mains Associates: Richard Mains for his comprehensive book concept and overall management of this project; Ruvanee Pietersz for research, writing, and translation of French material; Gretchen Gold for book production, illustrations, graphics, layout, and overall coordination; Wesley Rakeman for database development and management, and production assistance; Barbara Chan for book design, editing, illustrations, and publication project consultation; Alan Wood for database design; Karen Walker for content review and database production; Galina Tverskaya for translation of Russian material, review of material on the U.S.S.R./Russian space program, and conduct of Russian interviews; Melissa Padgett for several text illustrations; Richard Herron for most of the hardware illustrations; David Beckerman and Greg Leonard for production assistance; and Trisha Lamb Feuerstein for the index.

FOREWORD

Since the writing of this book began more than three years ago, extraordinary changes have taken place in Eastern Europe. The dramatic collapse of Communism in the former U.S.S.R. and the parting of the Iron Curtain that divided Eastern and Western Europe for over 40 years have transformed our view of the future. Many of the consequences of these changes are still uncertain. It is clear, however, that the references to the U.S.S.R. in this book are outdated. Since the book was written from the perspective of 1990, we have let this terminology and the description of the former U.S.S.R. space agency stand.

It will be obvious, if perhaps surprising to some readers, that a majority of the space flight experiments described in this book were conducted on U.S.S.R. Cosmos biosatellites. The Cosmos Program was especially important for obtaining regular access to space for Ames Research Center during the 1980s after the Challenger disaster. Following the August 1991 collapse of the U.S.S.R., the tenth, and last, Cosmos mission in this series was launched in December 1992 with several U.S. experiments onboard. The Russians (formerly the Soviets) worked hard against great odds to conduct this mission as planned. The Russians are developing a commercial, improved biosatellite for future use by the international space life sciences community. Significant interest in this plan has been expressed by many space agencies, including NASA.

The major part of this book was produced directly from the Space Life Sciences Payloads Office (SLSPO) Flight Experiments Database (FED), which has been under development for about four years. It includes descriptions of both developing and completed experiments along with hardware and publications information. This book could not have been produced without the FED and is a good example of what computers and software tools can accomplish. The FED has now become a part of the SLSPO Data Archiving Project, a key element of the new NASA Headquarters Life Sciences Data Archiving program. This program will provide information similar to that in this book via an online database for direct user access through the National Space Science Data Center (NSSDC), Greenbelt, Maryland.

This book intentionally has no concluding chapter, since it describes the results of ongoing research supported by the SLSPO at Ames Research Center. Although the future can never be projected with much accuracy, it promises to be as varied as the past in terms of the types of space flight missions undertaken. In addition to new biosatellites, new options on the Russian Mir space station, longer-duration Space Shuttles, and the International Space Station are being planned. Constrained funding has increased the trend toward international cooperation among space agencies. This trend was already accelerating due to the many advantages of coordinated research. Worldwide, the private and public sectors are collaborating more often to support space life sciences research and development. This book should be a useful resource for those prepared to participate in these opportunities.

1 Introduction

Life sciences research has been conducted in space for several decades. Initial U.S. efforts with biological payloads can be traced to 1946, when a collection of fungal spores was launched from Alamogordo, New Mexico, in a pioneering balloon flight. In the early years of the space age, the aim of life sciences research was to assess the ability of living organisms to survive space flight. Once it became apparent that animals and humans could withstand exposure to microgravity, cosmic radiation, and the rigors of launch and re-entry, the focus of inquiry shifted to the biological changes that occur during and after space flight.

A considerable body of knowledge has been gathered in this field. From both the mission and science standpoints, future generations of researchers can benefit from the achievements and lessons of the past only if the results are documented. This book is a record of the space life sciences research supported by the NASA Ames Research Center (ARC) Flight Experiments Program from 1965 to 1990. Life scientists and space industry personnel will find the book a valuable resource for guiding future research efforts. Laymen and students will also benefit from reading about the history of space life sciences research.

For the purposes of this book, life sciences research is defined as the study of biological and biomedical processes using live specimens as experimental subjects. All experiments conducted by or through the ARC, using microorganisms, cell cultures, plants, and animals are discussed here. A few radiation studies that used no biological materials are included because they accompanied the live specimens and are relevant to life sciences research. The significant research conducted by ARC in the areas of exobiology, life support, and other fields related to space life sciences is not considered. Studies undertaken by other NASA centers and experiments using human subjects are also outside the scope of this book.

This first chapter of the book discusses the objectives of life sciences research and the use of space as a laboratory. Although the book is written from a U.S. perspective, the increasingly international nature of space life sciences research is fully acknowledged. Chapter 2 addresses the interaction between NASA and foreign space agencies in implementing the ARC Flight Experiments Program.

Chapter 3 briefly describes the challenging process of developing an experiment for space flight. The program and mission descriptions in Chapter 4 comprise the major portion of the book. Commentaries by pioneers in space life sciences have been added when possible. Descriptions of ARC flight experiments are included in Appendix 1. Appendix 2 lists selected publications relating to these flight experiments. Appendix 3 contains descriptions of all the major hardware items flown on ARC-developed missions.

Life Sciences Research Objectives

Early space flight research was conducted simply to evaluate the viability of living systems in the microgravity environment. Later, researchers began to examine the changes that occur in such systems in response to microgravity. Today, research is increasingly

focused on attempts to understand the mechanisms for changes observed, and to develop methods to counter those changes.

Space life sciences research has two general objectives. The first is to study the effects of exposure to microgravity on biological systems to reduce the risks of manned space flight. The second is to use the microgravity environment to broaden scientific knowledge about the influence of gravity on living systems.

In mentioning these objectives, the importance of ground-based studies in simulated microgravity must not be forgotten. Many of these, such as bed rest, water immersion, and suspension studies were developed because it was difficult and costly to conduct research in space. Ground-based studies continue to provide information that is extremely valuable in helping to design and interpret experiments carried out in space.

Space as a Laboratory

The Space Environment

Where does space begin? It does not begin abruptly at an arbitrary point above the surface of the Earth (Fig 1-1). Broadly speaking, space can be said to begin just beyond the biosphere, which is the part of the universe in which life can be sustained without artificial support. The biosphere includes the land and sea masses of the Earth (lithosphere and hydrosphere) and the mass of air (atmosphere) above them. The atmosphere consists of a mixture of gases held in place around the Earth by gravitational forces. The density and pressure of the air declines as the distance from the Earth's surface increases. At an altitude of 12.20 km, no human can survive without an artificial atmosphere comprised entirely of oxygen. At an altitude of 18.29 km, a space suit or a pressure cabin becomes absolutely necessary for survival. "Physiological space" can be said to begin at this point. However, a finite atmospheric pressure of 54 mm Hg still exists.It is only at an altitude of 80.5 km that pressure

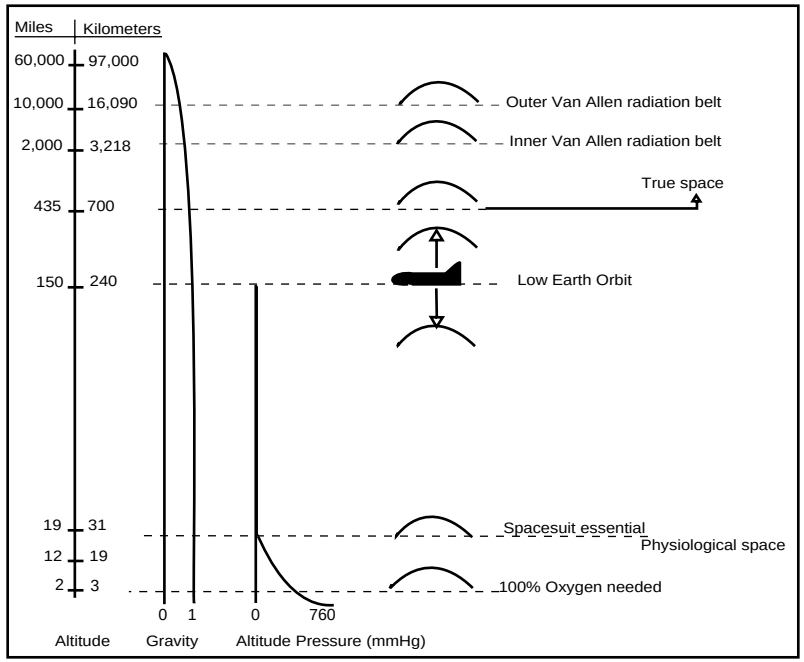

Figure 1-1: The transition from Earth's atmosphere to space (Harding 1989).

approaches zero, and not until an altitude of 700.35 km does a vacuum exist. This point can be considered to be the beginning of "true space." Even at this distance, the Earth still exerts a considerable gravitational attraction. It is theorized that no spacecraft launched from the Earth would be entirely free of the gravitational pull of the Earth until it was several million miles away. By then the gravitational effects of other celestial bodies would begin to have an effect. However, because an Earth-orbiting spacecraft is in "continuous free-fall," balanced by equal and opposite forces toward (gravitational) and away from (centripetal) the Earth, it is exposed to a very small force of gravity. The effective force of gravity may in fact be reduced to up to one millionth of its value on Earth (thus the term "microgravity").

Life forms have adapted to the force of gravity on Earth through millions of years of evolution. Gravity continuously acts upon living systems from microorganisms to humans. It is likely that the near absence of this force would evoke both acute and chronic changes in most biological systems. Investigation of these changes is the central theme of life sciences research in space.

The responses to microgravity thus far observed in animals and humans fall into three main categories. First, functional neurophysiological changes are known to occur as a result of the modified sensory input during space flight. Second, hormonal, humoral, and autonomic adjustments take place in response to a headward fluid shift. A third change occurs in the cardiovascular system and in bone and muscle tissue because of the absence of gravitational loading and the reduced necessity for physical activity in microgravity.

Space flight also exposes crew and passengers of spacecraft to radiation levels that are greater than either the background exposure at the Earth's surface or the occupational exposure for radiation and health workers. The source may be charged particles, neutrons, or ionizing photons. The risks of manned space flight can be assessed only after an accurate dosimetric picture of the space environment is available. Fluence, charge, velocity, specific energy, and time course of dose deposition must all be considered when predicting biological responses to radiation. Ground-based studies alone cannot provide this information. Ground-based studies rely on single sources of unidirectionally applied, monoenergetic radiation species. Some of these radiation sources do not exist or are insignificant in space. Shielding is usually not used in ground-based studies; it is always present in space. Furthermore, the potentially synergistic effects of microgravity and radiation cannot be determined from ground-based studies.

If humans are to live in space for long periods in the not too distant future, the physiological consequences of space flight must be thoroughly evaluated. Countermeasures must be developed to combat the detrimental effects of space flight to ensure health and productivity in this alien environment. In addition, hardware must be developed that is capable of providing adequate housing and life support.

The conditions of space flight, microgravity, and radiation (exclusive of the acceleration, noise and vibration levels encountered at launch and re-entry) cannot be reliably duplicated in ground-based simulations. Therefore, life sciences research ultimately must be performed and hardware design and operations must be verified in space.

We can increase our understanding of some fundamental biological processes by studying them in space as well as on the Earth. For instance, studying calcium metabolism and bone mineral depletion in space may provide insights into the clinical problems of bone decalcification and osteoporosis. The study of cardiovascular responses to body fluid changes associated with weightlessness may be useful in understanding the causes of hypertension and congestive heart failure. Likewise, the muscle deconditioning that frequently accompanies prolonged bed rest may be better understood by investigating similar changes in muscle structure and function that occur in response to microgravity.

The conduct of life sciences research in space is subject to numerous constraints. The high cost involved is a primary consideration. The cooperative spirit that has emerged between countries, in place of the intense competition of the early space age, has to some extent alleviated this problem. Joint space ventures between countries are advantageous because technology, resources, and scientific results can be shared.

Cost constraints also affect the choice of implementing research programs versus research projects. In an uncharted environment such as space, fruitful research can only be performed after initial exploratory studies are conducted. In other words, answers can only be sought after the correct questions are determined. Science objectives can, therefore, be better achieved through research programs encompassing several missions, although funding is often easier to obtain for research projects carried out on single missions.

One of the most difficult problems that researchers face is the fact that experiment technology frequently becomes outdated during the long period required for developing a mission. Preserving the flexibility to incorporate new technology is often difficult, especially if the mission is complex. Flight hardware designers have to finalize their plans several years before the planned launch date to ensure that there will be adequate time to fabricate and test the equipment.

Constraints influence not only the planning phase of a mission, but also the flight phase. Science requirements for various experiments must often be modified to meet mission requirements. Unmanned missions using nonhuman subjects require the development of fully automated life-support systems. Research on manned missions needs to rely less on automated hardware, although crew operations with animal subjects are usually very limited because of time constraints. At the same time, the complex issue of biologically isolating the animal subjects from crew members must be addressed.

Research Subjects

Although the ultimate objective of biomedical research in space is to ensure the crew's safety and well-being in the space environment, research using human subjects has serious limitations. Experiment procedures required for gathering important physiological data often cannot be implemented in humans for practical or ethical reasons. Research variables like temperature, diet, light cycle, activity, and stress cannot be easily controlled for humans. Continuous physiological monitoring using implanted sensors is not feasible. Crew members cannot usually be dedicated to specific in-flight experimental goals because of operational considerations. Data collected from crew members may be compromised by countermeasures taken to combat microgravity effects such as space sickness. Furthermore, crew members are rarely available for the extensive preflight and postflight analyses that constitute an important part of space flight studies.

For these reasons, nonhuman organisms often need to be used as research subjects in the space life sciences. These organisms can frequently be selected from a homogeneous population. Experiments using such subjects are not constrained by operational considerations. They can be allowed to adapt to the space environment without application of countermeasures. Environmental variables can be strictly controlled in-flight as well as during preflight and postflight ground-based studies. Measurements can be made using invasive techniques, tissue samples can be obtained, and drug testing can be carried out.

Various species of nonhuman subjects have been used in space life sciences research (see Table 4-2, p. 30). The use of vertebrate subjects, particularly mammals, is important because it is often possible to extrapolate experimental results to humans. Rats and primates are suitable experimental models for many studies. The adaptive responses of these animals have been studied in a number of biosatellite and Space Shuttle flights.

Non-mammalian vertebrates studied in space have included amphibians and fish. Among invertebrates, insects have been useful in experiments investigating the effects of microgravity and cosmic radiation.

Several experiments have been conducted on plants in space, including studies on germination and growth. Gravity plays a very important role in plant growth on Earth, enabling shoots to grow upward and roots to grow downward. Experiments conducted in space indicate that microgravity influences plant physiology, development, and metabolism. Research on the adaptation of plants to microgravity is obviously important if humans are to attempt to exist in space for long periods of time.

Lower organisms such as bacteria and fungi, as well as cell cultures, have also been studied in space. These simple life forms have enabled us to better understand biological processes that cannot be readily investigated in the presence of terrestrial gravity.

Additional Reading

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2 COOPERATION BETWEEN SPACE AGENCIES

This chapter describes the cooperative activities that ARC has undertaken in conducting research in space life sciences. Interactions between NASA and space agencies of other countries are reviewed in the context of this research.

In the 1960s and 1970s, the struggle for national superiority was one of the main forces driving the development of space activities. In contrast, international cooperation is now an important factor in many countries' space agendas. In 1958, the United Nations General Assembly created an ad hoc Committee on the Peaceful Uses of Outer Space (COPUOS). The committee now includes more than 50 member nations. The Scientific and Technical Subcommittee of COPUOS promotes scientific cooperation in outer space and provides technical assistance to developing nations in space-related matters.

Cooperation in space research benefits the international community in many ways. It allows scientific ideas, technical expertise, and facilities to be exchanged, and enables costs to be shared. Life scientists from around the world can collaborate effectively to solve problems of mutual interest. In addition to these advantages, there are political benefits to establishing cooperative enterprises.

National Aeronautics and Space Administration

NASA was created in 1958 to provide a formal structure for American civilian space activities dedicated to the peaceful uses and exploration of space. NASA now has several centers located around the country. Activities connected with space life sciences research are conducted primarily at four of these sites (Fig. 2-1). The Life Sciences Division at NASA Headquarters is responsible for overall program guidance and direction, and for integrating the activities of the various NASA centers. ARC in Moffett Field, California, Johnson Space Center (JSC) in Houston, Texas, and Kennedy Space Center (KSC) in Cape Canaveral, Florida, are responsible for implementing the life sciences research program. Activities at these centers include development of program and mission objectives, experiment selection, flight support, and data analysis.

JSC is concerned mainly with space biomedical research on human subjects. Life sciences research using nonhuman experimental subjects is conducted mostly at ARC. KSC carries out some life sciences flight experiments using plant subjects. Marshall Space Flight Center, together with KSC and JSC, also plays an important role in ARC flight experiments by supporting many preflight and postflight activities.

Ames Research Center

Although ARC was founded in 1939 as part of the National Advisory Committee for Aeronautics (NACA), NASA's predecessor, space life sciences research did not become part of the ARC agenda until 1960. Early life sciences research at ARC was concerned mainly with questions raised by preparations for the Apollo missions to the moon. Interest was centered on the effects of radiation, isolation, and changes in gravitational loading, and on crew life support requirements during space flight. Studies were also conducted on gastrointestinal function, tissue breakdown, and possible changes

in the processes of reproduction, development and aging in the space environment.

By late 1963, life sciences research was being conducted by four groups at ARC. The Environmental Biology Division focused on physiology, pathology, and radiobiology; the Biotechnology Division on human performance and man-machine interactions; and the Exobiology Division on biosynthesis and cell biology. The fourth research group was the Biosatellite Project Office, which was in charge of developing a series of unmanned biosatellite missions.

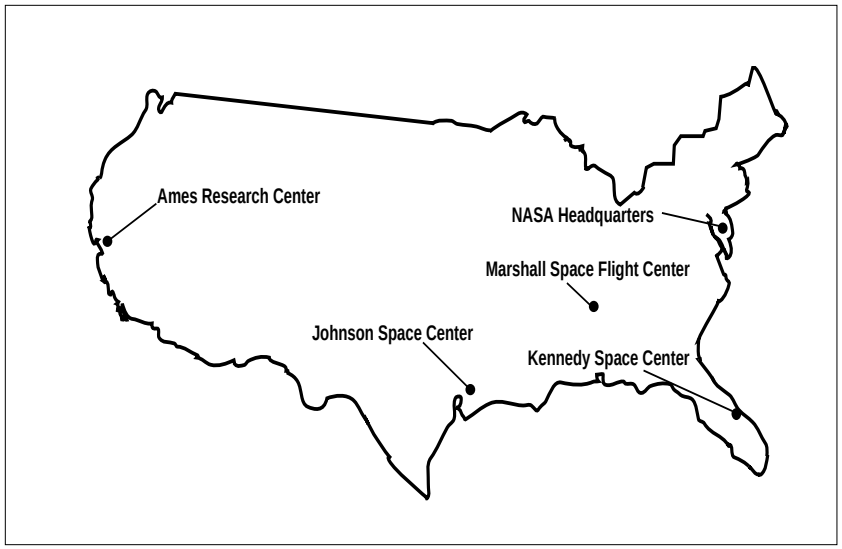

Figure 2-1: NASA facilities involved in life sciences research.

More resources became available for life sciences research beginning in 1963. During that year, a Bioscience Laboratory was built with an attached vivarium for housing animals. It was needed to accommodate the several hundred macaque monkeys that were expected to be maintained at ARC by 1965. These animals were to be used as space flight candidates for the Biosatellite Project. The facility supervisor was a veterinarian and a member of the National Animal Care Panel, established to ensure the humane treatment of experimental animals. The Laboratory had state-of-the-art surgery facilities, a recovery room, isolation wards, stainless steel animal cages, and steam sterilizing equipment.

A 20 g animal/human centrifuge became operational at ARC in 1964. It could simulate the stresses of spacecraft launch and re-entry. In 1965 a four-story Life Sciences building was completed for use in a wide range of research activities. Three long-duration animal centrifuges were available for hypergravitational studies by 1968.

Three biosatellite missions were developed by the Biosatellite Projects Office in the 1960s. The first mission, Biosatellite I, was launched in 1966. Because of a hardware malfunction, it was never recovered. Biosatellite II, launched in 1967, was a replicate of Biosatellite I. It carried several biological specimens into orbit and was successfully retrieved. Biosatellite III was launched in 1969, carrying onboard a single monkey. The monkey's untimely death, shortly after the biosatellite landed, focused a good deal of negative public attention on the Biosatellite research program. The controversy generated by this mishap, and the absence of plans or funds

for a follow-on project resulted in the dissolution of the Biosatellite Projects Office in the early 1970s. It was replaced in 1977 by the Life Sciences Flight Projects Office (LSFPO).

NASA began working on a concept for the Space Transportation System (STS) in 1969. In 1973, the Europeans agreed to build the Spacelab, an important element of the STS. In the mid-1970s, ARC conducted two initial simulation studies in conjunction with Marshall Space Flight Center and JSC. The objective of the studies (termed Spacelab Concept Verification Tests) was to verify the compatibility of life sciences flight experiments with the evolving design of the STS/Spacelab. A range of experiment subjects, including rats and rhesus monkeys, was used in the tests. Eventually, a life sciences payload was developed, which included human experiments from JSC. A seven- day flight simulation, termed the Shuttle Mission Development Test (SMD III), was then carried out at JSC to test this payload. By the conclusion of SMD III in mid-1977, the LSFPO had acquired its core staff and contractor support, and by the early 1980s had evolved into the current ARC Space Life Sciences Payloads Office (SLSPO).

In recent years, more resources have become available at ARC for life sciences research. A Vestibular Research Facility, developed in 1986, can deliver precisely controlled rotational and linear accelerations to animal subjects as large as young-adult macaques. The original Bioscience Laboratory has been expanded into an Animal Care Facility certified by the American Association for Accreditation of Laboratory Animal Care. An associated Biomedical Research Facility constructed in 1988 integrates animal housing and laboratories.

At the present time, life sciences activities at ARC are conducted within the Space Research Directorate. The Directorate comprises eight divisions and a staff of several hundred research scientists and engineers. Besides flight studies, the Directorate oversees ground-based research and new technology development.

Interagency Cooperation

NASA collaborates with other federal agencies and many universities in implementing its life sciences research program. Investigators from numerous academic and research institutions participate in the program. NASA is also pursuing opportunities with the National Institutes of Health (NIH) for joint biomedical and behavioral research. For example, a NASA-NIH workshop was held in 1989 to assess the similarities between the aging process and physiological deconditioning that occurs in space, and to discuss joint research in these areas. In 1992, the two agencies signed a memorandum of understanding that will enable them to carry out joint studies on such diverse subjects as neurological disorders, arthritis, and cancer. The Environmental Protection Agency is working with NASA to study the effects of global warming on aquatic systems NASA, the National Oceanic and Atmospheric Administration, and Farleigh Dickinson University's National Undersea Research Center are studying crews living in the Aquarius undersea habitat, as an analog to NASA's planned space station. NASA and the National Science Foundation are conducting joint

basic scientific and technical research in the Antarctic. The studies are expected to be applicable to developing a lunar base or a journey to Mars. There are also a number of joint projects in the life sciences between NASA and the Department of Defense.

Through the years, NASA has established a vigorous program of international cooperation to take full advantage of the limited access to space. This program is important in achieving NASA's objectives in the space life sciences. Cooperative activities can be initiated by a foreign agency asking to participate in a NASA program or by NASA suggesting international cooperation in a program. There are four types of agreements between NASA and foreign countries. Executive or intergovernmental agreements signed by officials of each government and processed by the U.S. State Department are established for high-cost programs like Spacelab. Other programs involve agency-level memoranda of understanding signed by the NASA administrator and his foreign counterpart, with State Department concurrence. Letters of agreement signed by the NASA International Affairs Division and its foreign counterpart can also be used for a wide range of programs. Some informal projects may be carried out with simple verbal agreements.

NASA is currently conducting joint research with several foreign space agencies, including the European Space Agency (ESA) and those of the U.S.S.R./Russia, France, Germany, Canada, and Japan. These activities are briefly described below.

U.S.S.R./Russia

Before its breakup in December 1991, the U.S.S.R. operated what was probably the most active space program in the world. However, its agenda was frequently shrouded in secrecy, probably due to a lack of separation between military and civilian space activities. Since the formation of the Russian Space Agency in 1992, a number of changes have been made in space policy. Space activities have become less prolific because of budgetary restrictions, but at the same time, they have become more visible because of the need for cooperation with other countries.

Before 1991, the Soviet Academy of Sciences played a lead role in U.S.S.R. civil space activity. The Intercosmos Council for International Cooperation in the Study and Utilization of Space was created by the Academy to develop cooperation with the Socialist satellite countries, and later Western Europe and the U.S. The Council was responsible for the initial international agreements in space life sciences research. It coordinated the activities of the Institute of Biomedical Problems in Moscow, which manages the Cosmos biosatellite program.

The Institute of Space Research (IKI), a division of the Academy, was also highly involved in international cooperative efforts. The planetary studies laboratory at the Vernadsky Institute of Geochemistry frequently collaborated with the IKI. The Glavkosmos agency was created to develop the commercial aspect of Soviet space activity.

The restructuring of the former U.S.S.R. space program in 1992 has led to a separation of military and civilian activities, with the Defense Ministry being responsible for the former and the Russian Space Agency for the latter. Ten of the former states of the Soviet Union may also jointly fund the civilian program.

There have been three areas of cooperation in the space life sciences between the U.S. and U.S.S.R. The first was exchanging data from flight experiments relating to the human response to space flight. Soviet data on the effects of long-term space flight on bone loss and cardiovascular deconditioning have been very useful to American researchers, especially because there were no manned U.S. flights during the period from the 1975 Apollo-Soyuz Test Project to the first Shuttle mission in 1981. Second, joint ground-based simulations of space flight conditions, such as long-term bed rest studies, have been conducted. The third area of cooperation was in basic biological and biomedical research. A joint U.S.-Soviet three-volume publication on Space Biology and Medicine was produced in 1975. A second edition is currently in preparation. Life sciences investigations were performed jointly on the Apollo-Soyuz mission. The U.S. also participated in the Cosmos series of biosatellite missions, to gather important data and to exchange information on problems of space biology.

An agreement for cooperation in space at the interagency level was first generated in 1962, between NASA and the Soviet Academy of Sciences. In 1971, a Science and Applications Agreement was signed between the U.S. and U.S.S.R., paving the way for joint studies in Space Biology and Medicine. This agreement was reinstated in 1987. In 1974, the Soviets offered to fly U.S. experiments on their Cosmos biosatellite for the first time. Since then, the U.S. has taken part in eight Cosmos biosatellite missions. Seven of these missions are described later in this volume.

Initial U.S. experiments on Cosmos consisted of "carry-on" packages, which were for the most part functionally independent, requiring no electrical power from the spacecraft. On later missions, U.S. experiments were carried out on rhesus monkeys and rats housed in Soviet animal habitats. On these flights, U.S. battery-powered instruments were integrated with Soviet spacecraft data systems to record biomedical data.

In 1992, a new agreement was signed between the U.S. and Russia to facilitate scientific and technological cooperation. A commercial contract was also drawn up between NASA and the Russian firm NPO Energiya. Through this contract, NASA will be able to use Russian technology in future U.S. missions, including the International Space Station.

The overall success of the U.S.-U.S.S.R./Russian collaboration in the space life sciences is due to several factors. Focused science objectives were important. The selection of complementary study areas provided a stronger incentive for cooperation. Instrumentation used in the U.S.-U.S.S.R. missions was carefully reviewed to avoid violating technology transfer regulations. A relatively flexible institutional organization on both sides allowed plans to be implemented in spite of a frequently difficult political environment. And finally, mutual confidence, knowledge, and goals have

developed between working groups with continuity of members over a long period of cooperation.

NASA plans to continue cooperative activities with the Russian Space Agency. A cosmonaut will fly on the U.S. Space Shuttle in the near future and a U.S. astronaut will spend some time on the Russian Mir Space Station. Substantial Russian participation is also expected on future U.S. missions, including docking the Space Shuttle with the Mir.

The European Space Agency

The ESA was formed in 1975 by 11 Western European nations. Member countries now number 13: Belgium, United Kingdom, Denmark, France, Ireland, Italy, The Netherlands, Spain, Sweden, Switzerland, Germany, Austria, and Norway. Canada has a technical agreement of cooperation with the agency. Headquartered in Paris, ESA has major facilities in The Netherlands, Germany, and Italy. Its principal objective is to achieve cooperation between member countries in developing space research and technology for peaceful purposes. Members contribute to ESA's general budget and mandatory scientific programs according to their gross national products. Each state also contributes voluntarily to optional ESA programs. A large percentage of ESA's budget is spent on financing contracts to European companies for building launchers, satellites, and other space flight hardware.

NASA has participated in numerous collaborative ventures with ESA. A formal Joint Working Group in the life sciences was established in 1986. The Spacelab was built under the auspices of ESA for the U.S. STS. Personnel have been exchanged between the two agencies. The ESA-built Biorack hardware was jointly used by NASA and ESA on the NASA-sponsored International Microgravity Laboratory missions in 1992 and 1994. ESA is also expected to be a major contributor to the International Space Station program, and will be responsible for Columbus, a module that is to be attached to Space Station. Germany and Italy have proposed using Spacelab-derived hardware to form Columbus.

France

As the primary space power in Western Europe, France, together with Germany, is the driving force behind the ESA. Before 1992, the Soviet Union collaborated in more space activities with France than with any other country. France was the third nation, after the U.S. and the U.S.S.R., to achieve national launcher capability, and now has significant capabilities in space manufacturing, Earth observations and telecommunications satellites.

The French Centre des Recherches de Medicine Aéronautique (CERMA) has existed, under different names, since the 1920s. Its activities are concerned primarily with aeronautical medicine; it investigates problems of physiology and medicine posed by the airplanes of the French Air Force. Until 1964, CERMA's space-related research was carried out directly with military teams. In 1964, the French government created the Centre National d'Etudes Spatiales (CNES) to study scientific and technical problems of a nonmilitary nature. From then on, CERMA experiments

Claude Milhaud

Claude Milhaud was trained as a veterinarian and is a graduate in physiology, biochemistry and psychophysiology. He is now a General in the French Air Force.

He entered the arena of space life sciences research in 1967, when he became involved in a project at CERMA. A year later, he began to study the pharma*cology and toxicology of substances that could kee*p human beings awake for several days. He studied monkeys, looking at how specific drugs affected their behavior and physiology. In 1974, NASA came to Europe to present the Shuttle Program and to solicit research proposals. During the same time, ESA proposed the construction of Spacelab. "We saw the value of the rhesus monkey model," says Milhaud, "so we suggested studying a system for maintaining monkeys in space." Monkeys seemed to be good human surrogates for space physiology experiments. He recalls the failure in 1969 of the American Biosatellite III mission. "We at CERMA found it surprising. But this disappointment made us more aware that the first priority of a space flight experiment was to bring healthy animal subjects back to Earth."

In 1975, CNES became interested in the CERMA project, and asked the French aerospace firm MATRA to preliminarily evaluate the experiments. This very rudimentary study was presented to the Congress of Aerospace Medicine in Tel Aviv in 1975. At the Congress, a session dedicated to space physiology was presided over by Professor Nello Pace, a primate physiologist from Berkeley, California. (See page 61.) Pace's interest was kindled by the presentation because of his own experiments with macaques. He invited the CERMA team to the U.S. to visit his laboratory and ARC, and to build contacts for a possible future collaboration between the U.S. and France. "My colleagues and I made our first trip to the U.S. in September 1976," Milhaud remembers. "That was the point at which the cooperation began."

From 1976 to 1980, Milhaud's team began developing a system that could be used for pharmacology experiments and for studies on the Space Shuttle. They used this system to conduct research with 12 restrained monkeys maintained in controlled environments. "We always kept in mind dimensions and shapes compatible with the Spacelab," Milhaud says. "We had regular contact with people from Ames and NASA Headquarters. They used to stop in Paris during frequent trips to the U.S.S.R. as participants of the Cosmos Biosatellite Program." A CERMA delegation also participated regularly in joint meetings with NASA. The idea for the French-U.S. Rhesus Research Facility project crystallized slowly through these meetings. Initially, the contacts between the two countries were mostly personal ones, but in later years relations have become more formal, and resulted in a NASA-CNES cooperative program focused on space research utilizing rhesus monkeys.

were controlled, progressively more rigorously, by CNES. Today, CERMA is a contractor to CNES like many university laboratories. CNES is responsible for all the space activities in France, and particularly for those concerning physiology and medicine.

CNES is the largest national space agency in Europe. It provides a framework not only for the French national space program but also for the French commitment to ESA. Although headquartered in Paris, CNES has its principal engineering and technology facility in Toulouse, and several other operating centers are located nationwide, including Evry and Guyanais. It also maintains two balloon-launching sites at Aire-sur-l'Adour and Gap Tallard. CNES is accountable to the French government's Ministry for Research and Industry. In recent years, the agency has established several companies and economic interest groups to commercialize space activities.

It is through CNES that bilateral space programs developed between France and other countries are managed. NASA has collaborated with France in space science and technology for several years. A Joint Working Group in life sciences was established in 1985. The two agencies conducted joint investigations on the International Microgravity Laboratory missions. A NASA-CNES program to fly 2 rhesus monkeys within a jointly-developed Rhesus Research Facility on a 16-day Space Shuttle mission was under development. It was halted in 1994 due to the absence of a manifested mission.

Germany

Until recently, the Deutsche Forschungs-und Versuchsanstalt für Luft und Raumfahrt (DFVLR), the aeronautics research establishment of West Germany, was the primary national agency involved in space activities. In 1989, the Deutsche Agentur für Raumfahrt-Angelegenheite (DARA), became the central management organization for German space activities. A state secretaries' committee on space chaired by the federal minister for research and technology is responsible for defining goals and commissions for DARA. The agency has the legal status of a private company with limited liability, and is owned and financed by the federal government. A cabinet committee on space chaired by the Chancellor provides programmatic and budgetary guidelines for space policy.

DARA represents Germany at the international level and is responsible for multilateral and bilateral agreements. It emphasizes manned and microgravity programs. Germany has been involved in the Columbus program and has had extensive manufacturing and manned flight experience with the European-built Spacelab. It was, in fact, the largest contributor to the Spacelab. The Spacelab D1 mission flown in November 1985 included a number of German-sponsored life sciences experiments. Spacelab D1 represented the first time that a foreign government leased an entire shuttle mission from NASA. German scientists flew scientific experiments on the 1991 Spacelab Life Sciences-1 mission, IML-1, and again on the Spacelab Life Sciences-2 mission in 1993. Another German payload was flown on the Spacelab D2 mission in 1993. Coupling of

studies carried out on Spacelab D2 and the Spacelab Life Sciences-1 and -2 missions benefited both countries.

Japan

Several national organizations are involved in Japanese space ventures. The Space Activities Commission was created in 1968 to coordinate and administrate space activities. The Science and Technology Agency provides the secretariat to the Commission, and is responsible for planning policy, developing international cooperation and promoting use of space. The Science and Technology Agency also controls the National Space Development Agency (NASDA), which was founded in 1969. NASDA is responsible for practical applications in space. Besides developing satellites and launchers, and launching, tracking and controlling satellites, NASDA promotes scientific experimentation in space. The National Space Laboratory is also linked to the Science and Technology Agency, and undertakes fundamental research in the space sciences. The University of Tokyo's role in space sciences has now been taken over by the Japanese Institute of Space and Astronautical Science. This institute carries out research and development activities on scientific satellites and launchers. In addition, several Japanese companies are constructing operational telecommunications satellites.

NASA established a Joint Life Sciences Working Group with Japan in 1985. Japan is in the process of building a national manned space program, using its experience in U.S. and international missions. Japanese scientists are involved in the International Microgravity Laboratory series of missions sponsored by NASA. The 1992 Spacelab-J mission was also a joint U.S.-Japan venture. Another important Japanese contribution to the international space effort is the Japanese Experiment Module, a pressurized microgravity facility that will be attached to the planned the International Space Station.

Canada

The Canadian Space Agency was formed in 1989, drawing together the space activities of the Ministry of State for Science and Technology, the Department of Communications, the Department of Energy, Mines and Resources, and the National Research Council. The agency manages the civil space program, which includes the development of space science and technology and the astronaut program. Canada's involvement in international space activities arises through its associate membership in the ESA and its long history of close collaboration with NASA.

Canada developed the Remote Manipulator System for the U.S. Space Shuttle, making it the largest national contributor to the STS outside the United States. Canadian experiments have been flown on several Shuttle missions and some have included Canadian scientists as crew members. Canada plans to provide a Mobile Servicing Station for the International Space Station, which will be critical for assembling, maintaining, and servicing the station. Canada is also expected to participate in materials sciences and life sciences research on the space station.

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3 FLIGHT EXPERIMENT IMPLEMENTATION

Conducting a life sciences experiment onboard a spacecraft can be a formidable task (Fig. 3-1). Designing experiments, assembling the necessary resources, building the appropriate hardware, conducting innumerable tests and coordinating experiments with missions are time-consuming, complex activities. The entire effort may take from 2 to 10 years, depending on the nature of the experiment and the mission (Fig. 3-2). The need for ground-based control studies to verify the scientific validity of inflight data further complicates the process.

The major activities involved in carrying out an experiment in space are described for two cases. The STS program represents a situation where experiments can be performed in manned spacecraft. In such cases the experiment design, types of animals, hardware used, and preflight and postflight operations must be compatible with crew safety requirements. The Cosmos Program is an example of a situation where experiments can be conducted in an unmanned vehicle. In this case, experiments are not constrained by crew

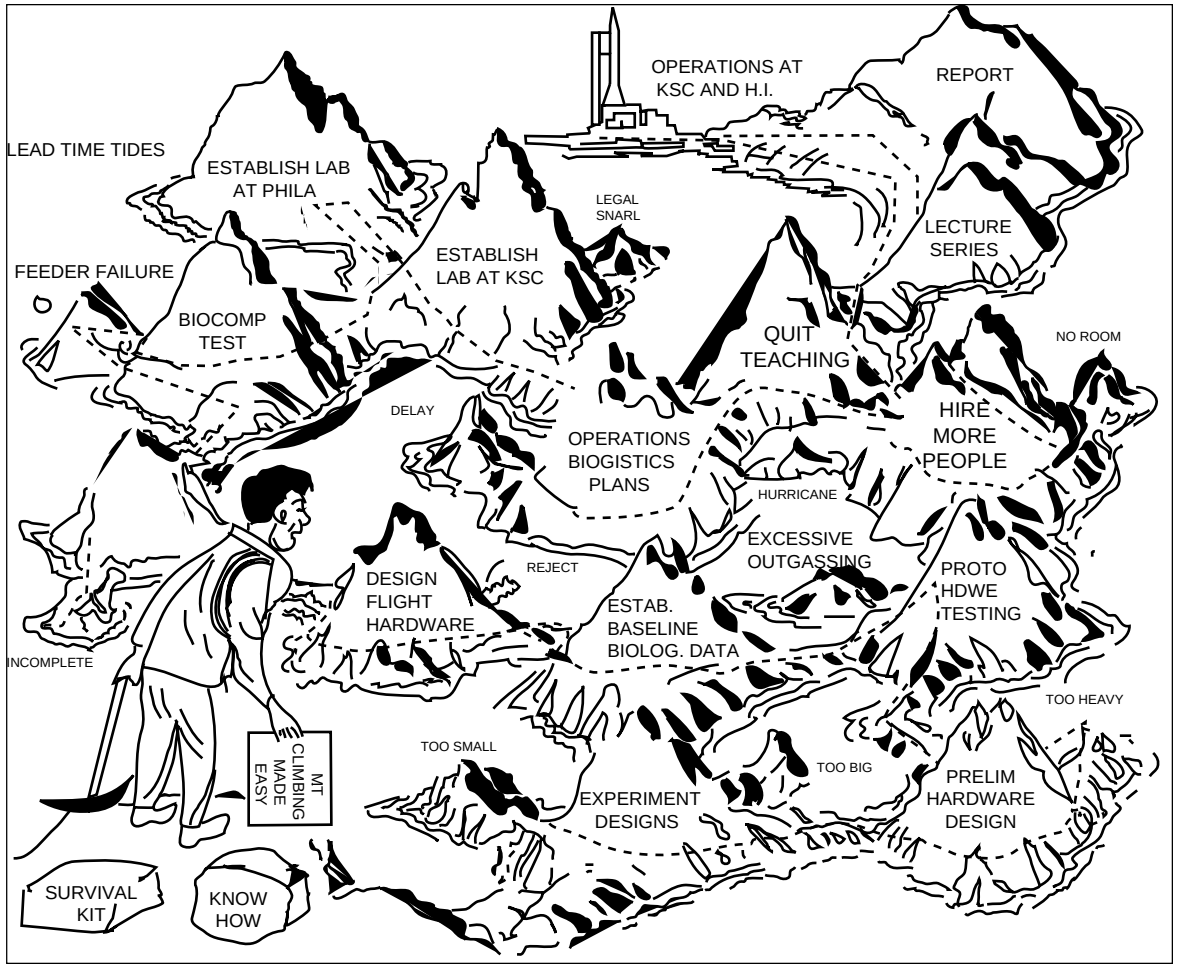

Figure 3-1: The space life science researcher's story from the U.S. Biosatellite era . Adapted from the American Institute of Biological Sciences, Experiment Survey Program, Biosciences, U.C. Berkeley,1968.

safety standards, but they must rely on automated hardware because inflight crew manipulations are not possible.

Experiments on the Space Transportation System

Preparation of a payload for flight on the STS occurs at three levels: experiment, payload, and mission (Fig. 3-3). Objectives, design, and hardware requirements must first be developed for individual experiments. All of the experiments must then be integrated into a single payload which satisfies the requirements of each experiment. Finally, this payload must be incorporated into a designated mission. This means that the payload must accommodate the constraints set on the mission by other payloads, by the design of the spacecraft, and by crew safety and operation requirements.

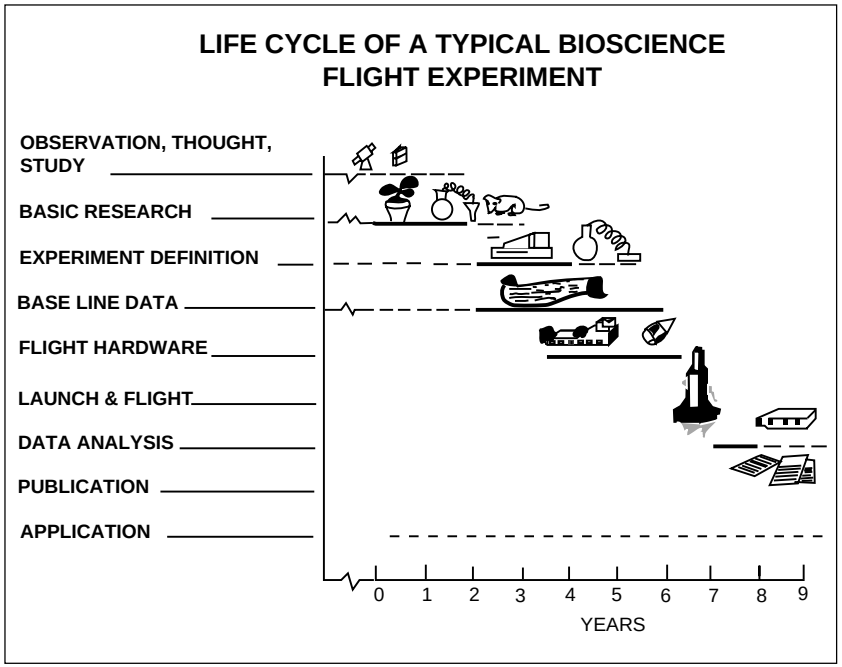

Figure 3-2: Life cycle of a typical life science flight experiment from the U.S. Biosatellite era. Adapted from American Institute of Biological Sciences, Experiment Survey Program, Biosciences, U.C. Berkeley, 1968.

NASA conducts at least three reviews at each preparatory level. These are the Preliminary Requirements Review (PRR), the Preliminary Design Review (PDR), and the Critical Design Review (CDR). Through these reviews NASA maximizes the potential for implementing a successful life sciences experiment in space. The three reviews within a level progressively refine the experiment, payload, or mission. The results of the reviews from one level are fed into the next level of development.

Experiment Development

Selection

NASA receives both solicited and unsolicited proposals for flight experiments from researchers in various life sciences disciplines. NASA, or an external agency selected by NASA, evaluates the scientific merit of each proposal through a peer review process. ARC, JSC, or KSC determines the feasibility of conducting each proposed experiment in space. They address engineering and experiment development costs, management requirements, and availability of NASA resources. NASA Headquarters then selects a subset of feasible experiments. This is the candidate pool from which experiments are finally chosen for definition.

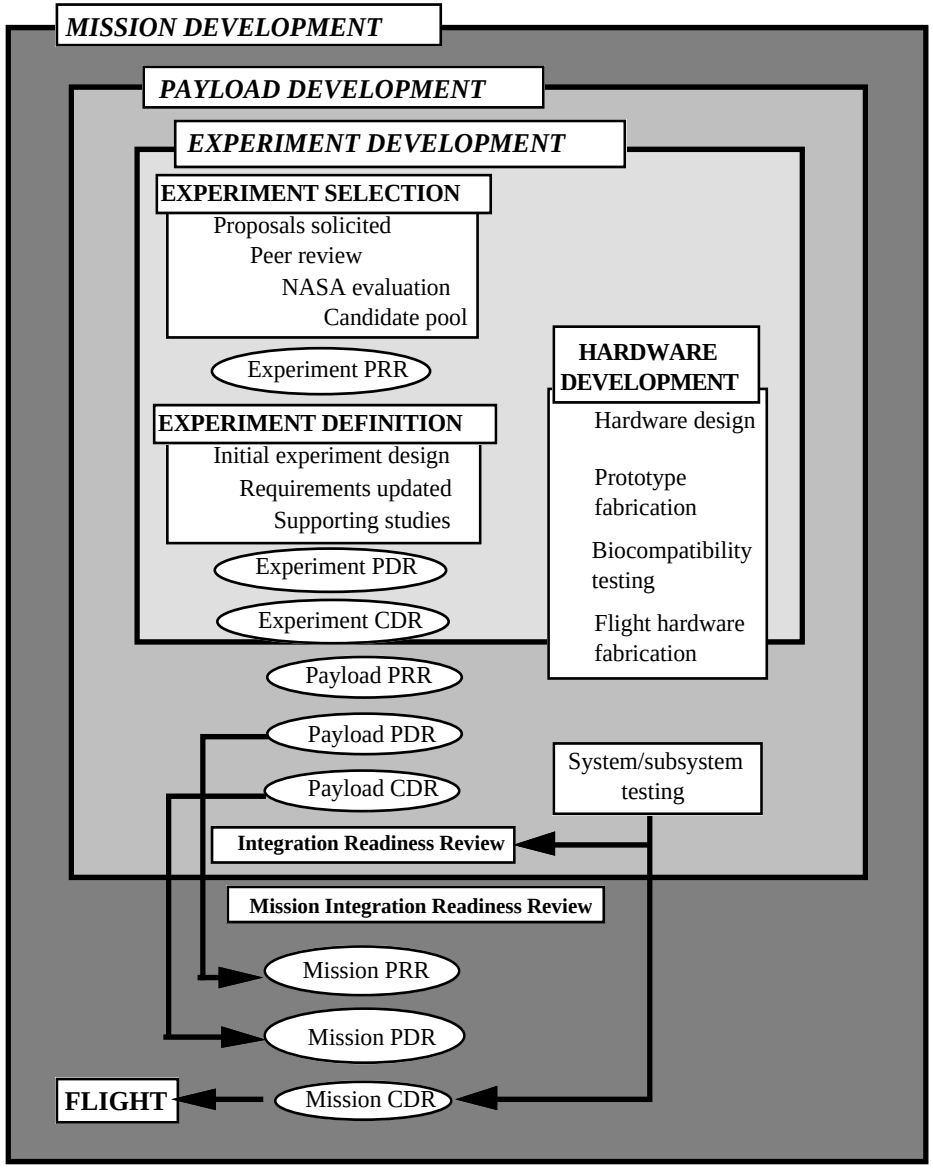

Figure 3-3: Preparation of a payload for a Space Shuttle mission.
- *PRR: initial design formulated.*
- *PDR: design reviewed and hardware requirements incorporated.*
- *CDR: design finalized and building of flight hardware approved.*

Three major factors are considered when assigning experiments to a particular mission. First, scientific yield from different research areas has to be maximized. Second, there must be minimal interference between experiments. Finally, maximum use must be made of common facilities, sensor systems and data processing equipment.

Definition

Detailed definition of experiment requirements begins after a contract or grant is negotiated between an investigator and NASA. Several issues must be addressed to fully define an experiment (Table 3-1).

The science objectives of the experiment must be clearly formulated and the feasibility of conducting the experiment in space carefully evaluated. The resources required for developing the experiment must be available. Ground-based operations necessary for conducting the flight experiment, and supporting studies to assess experiment feasibility, must also be defined.

Requirements are updated as the experiment undergoes continuous refinement. Supporting studies are conducted to provide baseline data for each experiment. Such studies are initiated early because they affect the experiment's overall design. If the initial design does not receive NASA concurrence, new approaches are considered.

Science Objectives

- Hypothesis
- Experiment Goal
- Research Subjects

Hardware/ Data Requirements

- Housing for Research Subject
  - -provision of food and water
  - -suitable environment
  - -waste collection
- Measurements
  - -physiological
  - -environmental

Mission Constraints

- Size of Payload
- Weight of Payload
- Power Requirements of Payload
- Thermal Issues

Safety Considerations

- Biological Isolation
- Flammability/Offgassing of Hardware

Equipment/Science Verification Procedures

- Data Acquisition Capability of Hardware
- Biocompatibility of Hardware
- Feasibility and Value of Science
- Supporting Studies

Operations

- Crew Training
- Preflight, In-flight, and Postflight Procedures
- Ground Support Equipment
- Logistics

Table 3.1: Issues addressed during development of a flight experiment.

Hardware Development

Hardware must be specially built or modified to suit the space environment. Flight hardware is designed to meet stringent requirements pertaining to safety, mass, mechanical operation, structural features, electrical power usage, computer interfaces, and thermal properties. Safety standards must be verified and meticulously recorded. In addition, all flight hardware must be tested to verify that it can withstand the mechanical and acoustic vibrations encountered during launch, the acceleration forces (up to 3.2 g) during ascent into orbit, and the microgravity conditions in orbit.

Flight hardware includes equipment for housing the experiment subjects and monitoring their health and general well-being. Individual experiments sometimes require that special hardware be designed and fabricated (experiment unique equipment (EUE)), in addition to general purpose multi-user flight hardware. Hardware prototypes are fabricated during the experiment development phase. They must be compatible with the design and safety requirements of the STS and be able to withstand the stress of launch and re-entry. At the same time, appropriate system interfaces are designed and procedures for instrument verification developed. Prototype hardware designs are reviewed twice before flight hardware is fabricated. Existing ground hardware is also evaluated for potential transition to flight application at this time.

A formal review is conducted once the experiment and hardware design is completed and formally defined. After acceptance at this review, the experiment is ready to be incorporated into a payload.

Payload Development

Payload development is the process by which individual experiments are combined into a cohesive package. It is analogous to and frequently proceeds in parallel with the experiment development process. The results from individual experiment and hardware reviews provide input to the formal payload review processes.

Flight hardware is developed during this phase. Besides the items that are actually flown on the Shuttle, this hardware includes flight and ground data systems and special ground support equipment, such as checkout equipment for interface verification and functional tests. All flight hardware is subjected to verification testing and formal reviews.

A payload must undergo testing at the subsystem and system levels. Two main tests are conducted at the system level. The first is a Biocompatibility Test, so called because it is used to assess the compatibility of the hardware with the biological environment (including research subjects). The second is the Experiment Verification Test (EVT), which uses a simulated mission timeline and simulated flight conditions to verify the effective interaction of experimental procedures, hardware, and personnel.

In addition, the readiness of the payload for integration into a mission must be evaluated before it is shipped to KSC. Once it is demonstrated that the mandatory verification procedures have been performed, the payload is ready for physical integration into the Spacelab or the Shuttle middeck at the launch site.

Training of flight and ground support personnel is an important part of any space flight mission and is often conducted in specialized facilities. These may be equipped with flight hardware mockups, mathematical models, or payload simulators such as the Spacelab simulators provided for crew training at JSC and Marshall Space Flight Center (MSFC).

Payload Integration

Payload reviews generate results which provide input to the reviews held at the mission level. All requirements from various payloads must be combined to ensure mission success. During this period, hardware is fitted into the spacecraft, mission support personnel are acquired, and the crew is trained. The compatibility of the payload with the STS and with other payload elements, and overall system safety must be confirmed. Much of this activity takes place at KSC. ARC's involvement, and that of the investigators, is essential throughout this phase.

Investigator's Role

The investigator plays an important role during the entire payload development phase. Investigator Working Groups are established during the experiment definition phase to coordinate the requirements of different experiments. Investigator input is critical when evaluating the capability of the hardware to meet experiment requirements, and during biocompatibility testing. The investigator must help train crew members to familiarize them with experiment requirements and in-flight procedures. The investigator also

assists in evaluating payload design in relation to the defined experiment requirements and in reviewing payload integration and checkout.

Science support facilities at ARC, KSC, MSFC, and JSC give investigators access to in-flight data while the mission is in progress. These facilities also enable investigators to communicate with crew members during the mission.

Flight Phase

The flight phase begins at launch. Once the spacecraft reaches orbit, crew members follow a minute by minute schedule to accomplish the mission and experiment objectives. During these operations, the crew can consult with investigators via two-way voice communications, air-to-ground telemetry (data transmission), and television.

In-flight data is displayed simultaneously onboard and in the Science Operations Area at the MSFC. This data can also be transmitted to Test Monitoring Areas at ARC, JSC, KSC, and remote laboratories.

Operations that take place on the ground during the flight phase are as important as those that occur onboard the spacecraft. The Mission Control Center at JSC is responsible for monitoring and providing contingency support for orbiter payloads, two-way communications with the crew and onboard systems, and transmitting flight data to a central site. It also communicates with the Payload Operations Control Center (POCC) for coordinating flight operations between orbiter and Spacelab payloads. The POCC houses data monitoring facilities and commands payload elements in the Spacelab while maintaining communications with the Mission Control Center and the crew.

Pre/Postflight Operations

Preflight studies are frequently conducted several months before the mission to collect baseline data for flight experiments. Many investigators also require preflight collection of biosamples or data. During this period, investigators use laboratory facilities at various NASA centers to prepare experimental subjects for flight and to take preflight baseline measurements.

Special facilities are situated at launch and landing sites for harvesting and processing biospecimens, and for preflight data collection. For instance, the Life Sciences Support Facility at KSC is used for preparing and analyzing nonhuman biospecimens. Available resources include common laboratory supplies and analytical instruments, and animal maintenance facilities.

Experimental subjects are usually loaded into the Spacelab about 30 hours before launch and may be removed from the spacecraft as early as 3 hours after landing. Middeck payloads can be loaded about 18 hours before launch. Data collection commences at a facility situated at the landing site. Special arrangements are made if the orbiter is forced to land at a secondary or contingency site.

Experiments on Cosmos Biosatellites

U.S. scientists have conducted many experiments within the Soviet Cosmos biosatellite program. Experiments on the Cosmos biosatellite differ from those carried out on the Space Shuttle mainly because of one important factor. Since the biosatellite is unmanned, all in-flight experimental operations must be automated, as must all spacecraft subsystems and life support systems for experimental subjects. The biological subjects cannot be directly observed, although video viewing is possible. Repair or manual regulation of the life support system or the experiment hardware is not possible in flight, as are even the simplest of experimental operations. An unmanned satellite, therefore, has special demands for quality and reliability, especially in the equipment that provides automatic control and remote monitoring during the course of the flight experiments. This need for automation places some constraints on the types of experiments that can be performed on the biosatellite. Additionally, extensive shock and vibration testing needs to be carried out because of the impact of landing.

There are, nevertheless, distinct advantages to using unmanned vehicles for experimentation in space. The overall cost per mission is considerably less than for a manned mission. A wider range of materials can be used in hardware fabrication because crew safety is not a consideration. For the same reason, experiment design is more flexible. Missions can be terminated early if necessary or extended to maximize science return without concern for the requirements of the crew.

Experiment Development

Selection

Flight programs are developed by the U.S.S.R./Russia. The forum for presenting these program scenarios is frequently at meetings of the Joint Working Group for Space Biology and Medicine. At these yearly meetings, joint projects are discussed. Experiment proposals are invited from the U.S. and other participating countries. Once proposals are accepted and approved by Russian specialists, plans are exchanged on the best means of implementing the studies.

Definition

Experiments submitted by U.S. investigators are conducted jointly with Russian counterparts. Tissue samples and data are frequently shared between the two countries. In some cases, Russian and U.S. investigators perform complementary analyses of flight data, thus enhancing the science of both countries.

A key document, the Experiment Management Plan, is prepared for each experiment. This plan is a comprehensive summary of the experiment objectives, data, equipment, and operational requirements. It also outlines the agreements made between Russian and U.S. scientists with respect to data sharing and provision of equipment. The document is regularly updated, providing a means for recording the experiment's evolution to a state of readiness for flight.

Hardware

On the first three Cosmos missions with U.S. participation, most U.S. experiment hardware was in self-contained packages during the flight. Life support for the experimental subjects was provided mainly by the Soviet spacecraft environmental control system. These packages were delivered to the U.S.S.R. after flight qualification testing was performed in the U.S. The packages were installed in the spacecraft, flown in Earth orbit, and then returned to the U.S. Rodent and primate housing systems have always been provided by the U.S.S.R. In recent years, hardware development for the Cosmos experiments has become more of a joint effort. From the time of the first primate mission, Cosmos 1514, the U.S. began to supply hardware that required integration with Soviet equipment. On these later missions, U.S.-built hardware was often used to obtain physiological data. Such collaboration demanded joint verification testing and greater cooperation between the two partners.

U.S. flight hardware is subjected to extensive testing to ascertain that it can withstand launch, space flight, and the impact of biosatellite landing. Although testing is thorough, documentation is kept to a minimum.

Payload Development and Integration

Russia develops and integrates the payload. U.S. representatives are in frequent contact with Russian specialists. Experimental techniques are verified in the U.S. using animal subjects similar to the Russian flight subjects. Training sessions and development of detailed procedures are necessary since Russian and U.S. investigators collaborate closely in many of the preflight and postflight activities. Such activities include sensor implantation, biosampling, tissue preservation, and other experiment operations.

Complicated logistics and differences in language and metho dology sometimes hinder coordination of Russian and U.S. activities. A true cooperative spirit has been important in circumventing these difficulties.

Investigator's Role

U.S. investigators conducting experiments on the Cosmos biosatellite are not typically involved in mission logistics. Researchers base their experiments on the guidelines of the mission plan provided by the Russians. Investigators conduct preflight testing to ensure the suitability of techniques and hardware, which is essential to experiment success. In some cases Russian personnel are trained to conduct experimental procedures in the investigator's absence. Investigators frequently travel to Russia before the flight. Although they do not take part in any launch or landing activities, they are able to perform preflight/postflight testing on the flight animals during a certain window of time before launch and after recovery. Biosamples from experiment subjects are processed by U.S. investigators either in Russia or at their own laboratories.

The Flight Phase

In the past, the launch of the biosatellite has been a closed event and participation by foreign representatives has rarely been invited.

Flight duration is determined by the program of scientific studies. While in orbit, the onboard systems of the satellite operate in accordance with the flight program. Animals are allowed access to food and water according to a specific schedule. An automatic lighting system provides simulated day and night periods. Radio telemetry is used to control the flight subjects' environment and the spacecraft systems. Russian ground stations track the path of the biosatellite.

Pre/Postflight Operations

Preflight studies are conducted in the U.S. several months before the launch. U.S. investigators conduct some limited preflight and postflight operations, but in most cases Russian specialists handle flight animals.

Unlike the Space Shuttle, the Cosmos biosatellite does not land at a specific site. An automatic landing system controls the descent of the biosatellite's landing module. As the module moves through the Earth's atmosphere, a parachute system becomes operational, which cushions the impact of landing. Radio direction finding equipment is used to locate the biosatellite.

Once the biological subjects are recovered, immediate postflight operations are conducted in a temperature-controlled field laboratory erected at the landing site. Primates are examined upon recovery and then shipped to Moscow for testing.

Processing of other biospecimens begins three or four hours after landing. Tissue samples requested by U.S. investigators are preserved or frozen according to instructions, and later shipped to the U.S. If required, postflight testing is performed after the subjects have been transported to Moscow.

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4 Programs, Missions, and Payloads

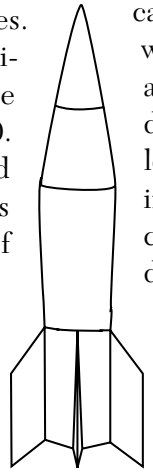
Overview

Space life sciences experiments conducted between 1965 and 1990 are summarized in this chapter. Missions conducted before 1965 occurred before life sciences research had been established at a specific NASA center. The post-1965 missions were developed by ARC, and are the primary focus of this book. Each mission is described in subsequent sections of this chapter.

Biological Payloads Before 1965

The first U.S. effort at sending biological payloads into space was probably in late 1946, when a balloon flight was launched from Alamogordo, New Mexico. The intent was to study the effect of cosmic radiation in the upper Earth atmosphere on fungal spores. The flight was unsuccessful because the spore containers were not recovered. Another flight was made a year later, using fruit flies. The payload was recovered successfully after attaining an altitude of 170 km. No effects of cosmic radiation were noted. The balloon flight program began to gain momentum around 1950. More than 30 balloon flights were conducted between 1950 and 1954. Fruit flies, mice, hamsters, cats, dogs and rhesus monkeys were flown to altitudes ranging from 27-30 km for durations of up to 28 hours.

By this time, interest had also become focused on suborbital rocket flights. Rockets had been in evidence for many years, but the solid fuel engines in use were not suitable for reaching very high altitudes. The first liquid fuel engine to become operational was the V-2 rocket designed by the Germans. After World War II and the capture of German V-2 rockets, the U.S. began to use vehicles of this type to study the ionosphere. Biological specimens were used frequently on these flights to obtain information relating to human survival in space. At least nine V-2 rockets were flown between 1946 and 1948, with payloads containing seeds, fungal spores, and fruit flies.

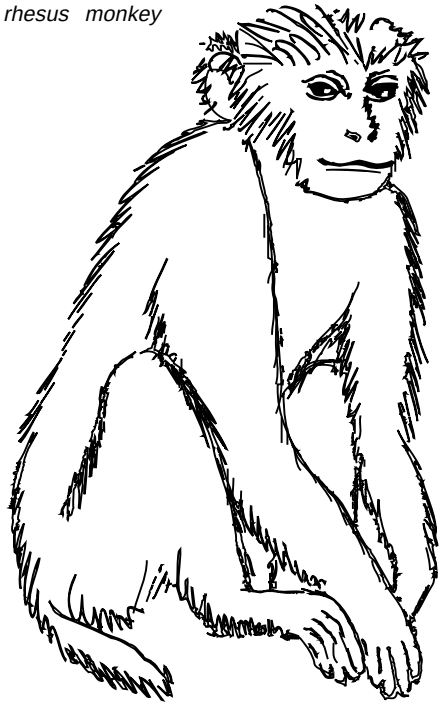


V-2 rocket

From 1948 to 1952, a series of eight vertical rocket flights was launched to gather physiological data about the effects of suborbital flight on monkeys and mice. A capsule capable of carrying a non-human primate was constructed for the first flight in the series, together with a system for telemetry of physiologic data. The capsule housed an anesthetized rhesus monkey named "Albert" within the nose cone of the rocket. The monkey was restrained in an extended position, by means of nylon netting, in a specially designed couch padded with sponge rubber. A thermocouple located in a rubber face mask monitored respiration. Electrodes in the leg and chest were used to record electrocardiograms. The capsule was not recovered because the parachute failed to deploy during descent. A second capsule with a rhesus monkey was launched a year later, to an altitude of 133 km. The parachute failed again during descent, and the recording equipment

onboard indicated that the animal died on impact. The next two flights each carried a cynomolgus monkey; neither animal was recovered. An unanesthetized mouse was launched in 1950, on the last V-2 flight in the series. The animal was photographed at intervals throughout flight. Although the mouse died on impact, the camera and film were recovered. Analysis of the recovered data showed that the mouse oriented itself by using tactile and visual cues during the brief period in microgravity.

Macaca mulatta, *rhesus monkey*



By 1949, the U.S. had developed the Aerobee, a high-altitude, fixed-fin stabilized, free-flight rocket. The first Aerobee flight with a biologic payload was launched in 1951. The anesthetized cebus monkey onboard was not recovered because of parachute failure. Five months later, a second Aerobee flight was launched to an altitude of 71 km and the payload successfully recovered. The rocket carried a single instrumented rhesus monkey and 11 unanesthetized mice. Electrocardiogram, respiration, and arterial and venous pressure measurements were performed on the monkey. Nine of the mice were used in a study of the effects of cosmic radiation. The two remaining mice were flown inside a special drum that rotated about an axis transverse to the long axis of the rocket. One compartment of the drum contained a labyrinthectomized mouse; the other contained a normal mouse. The mice had to climb over a smallpaddle located in each compartment and their performance was photographically recorded. Interestingly, the labyrinth-defective mouse performed well in the weightless condition, while the normal animal displayed marked disorientation. The rhesus monkey died from heat exposure soon after landing, because the recovery team reached the landed capsule only after some delay. The last flight of the series, Aerobee 3, was launched in 1952. Two cebus monkeys were flown, together with two mice (one labyrinthectomized and one normal). The experiment with the mice confirmed the results of the previous flight. One of the monkeys was placed in a seated position to receive exposure to +Gz (head to tail) acceleration, and the other in a supine position to receive +Gx (chest to back) acceleration

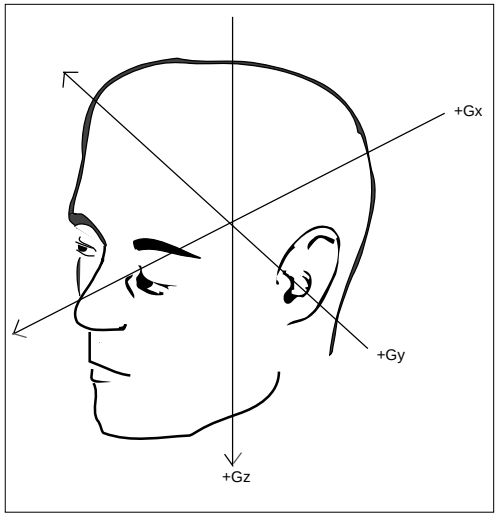
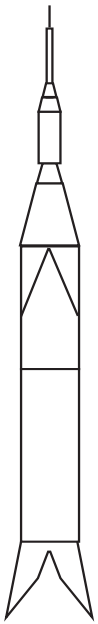


Figure 4-1: Vector designations for acceleration.

(Fig. 4-1). Both monkeys and mice survived the flight without noticeable ill effects.

In mid-1958, a mouse named Wickie was sent into space in the first flight of the "Mouse in Able" program. The biological capsule was flown in the nose cone of a Thor-Able missile combination to experience a 20-minute period of weightlessness. The mouse was not recovered. A single mouse was flown on each of the next two flights of the program. Because of conflicting reports, it is not clear if these mice were recovered safely . However, physiological data were telemetered to the ground during the flight period, and the mice did survive re-entry into Earth's atmosphere.

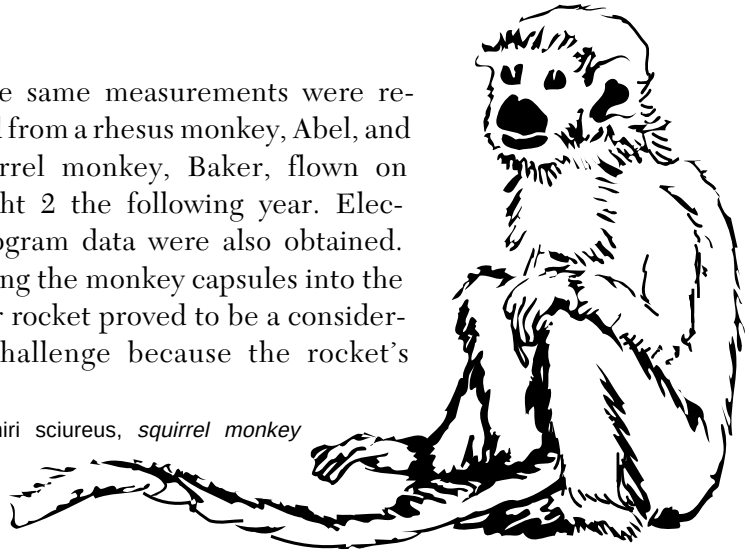


Jupiter rocket

Later in 1958, Bioflight 1 launched an unanesthetized squirrel monkey, named Old Reliable, in a Jupiter rocket. The rocket attained an altitude of about 480 km. Telemetered data on heart rate, heart sounds, body temperature, and cabin temperature, pressure, and radiation were obtained. A respiration rate sensor was installed but did not function. The life support system functioned well. The animal was not recovered.

Pan troglodytes, *chimpanzee*

The same measurements were recorded from a rhesus monkey, Abel, and a squirrel monkey, Baker, flown on Bioflight 2 the following year. Electromyogram data were also obtained. Inserting the monkey capsules into the Jupiter rocket proved to be a considerable challenge because the rocket's nose cone was not designed to accommodate a biological payload of this size. Abel had to be installed in the nose cone three days before launch. During the time on the launch pad, he was fed intraperitoneally; wastes were allowed to accumulate in diapers. An attempt was made, for the first time, to collect data on performance parameters during flight. Abel was trained to tap a switch when a red light flashed in the capsule. Unfortunately, data from the performance test system was lost before takeoff. The capsule was successfully recovered. Abel died five days after the flight during anesthesia for electrocardiogram implant removal, but Baker survived.



Saimiri sciureus, *squirrel monkey*

About a week after the Bioflight 2, four mice were launched in a Discoverer 3 satellite in the first U.S. attempt to orbit a biological payload. The satellite failed to achieve orbit, and the payload was never recovered.

In 1959 a rhesus monkey, Sam, was sent to an altitude of 84 km in a Little Joe solid fuel launch vehicle. Performance tests were conducted and results successfully recorded. The flight was repeated in 1960, with another monkey named Miss Sam. Equipment for the manned Project Mercury was verified on the two flights. Both flights were successfully recovered. A fungus experiment launched on a Nuclear Emulsion Recovery Vehicle (NERV) capsule in 1960 was also recovered.

Important information on radiation was gathered during a 1960 flight that carried three mice to an altitude of 650 km. An Atlas RZX-2A missile was employed to boost the animal capsule. Orbit was not achieved, but the capsule did pass through the inner Van Allen belt (a high radiation zone encircling the Earth). No adverse effects of radiation were noted in the animals after recovery.

Before man attempted orbital flight, primates were used to gauge survivability during space

Mission Payload	Spacecraft/Launcher	Launch Data
Gemini 3/Sea Urchin Experiment	Gemini/Titan 2	03/23/65
Gemini 8/Frog Egg Package	Gemini/Titan 2	03/16/66
Gemini 12/Frog Egg Package	Gemini/Titan 2	11/11/66
Biosatellite I/Experiments capsule	Biosatellite/Thor Delta	12/14/66
Biosatellite II/Experiments capsule	Biosatellite /Thor Delta	09/07/67
Biosatellite III/Primate Experiments capsule	Biosatellite/Thor Delta	06/28/69
OFO-A/FOEP	OFO /Scout	11/09/70
Apollo 17/BIOCORE	Apollo/Saturn V	12/17/72
Skylab/CPE	Saturn V/IB	07/28/73
Cosmos 782/Bion 3	Vostok (mod)/Cosmos C	11/25/75
Cosmos 936/Bion 4	Vostok (mod)/Cosmos C	08/03/77
Cosmos 1129 /Bion 5	Vostok (mod)/Cosmos C	09/25/79
STS-3/OSS-1	Columbia/STS	03/22/82
STS-8 /SSIP	Challenger/STS	08/30/83
Cosmos 1514/Bion 6	Vostok(mod)/Cosmos C	12/14/83
STS-10/SSIP	Challenger/STS	02/03/84
STS-51B/Spacelab 3	Challenger/STS	04/28/85
Cosmos 1667/Bion 7	Vostok(mod)/Cosmos C	07/10/85
STS-51F/Spacelab 2	Discovery/STS	07/29/85
Cosmos 1887/Bion 8	Vostok(mod)/Cosmos C	09/29/87
STS-29/SSIP	Discovery/STS	03/13/89
Cosmos 2044/Bion 9	Vostok(mod)/Cosmos C	09/15/89
STS-34/GHCD-01	Atlantis/STS	10/18/89
STS-32/CNCR	Columbia/STS	01/10/90
STS-41/PSE-01	Discovery/STS	10/01/90

Table 4-1: Mission directory.

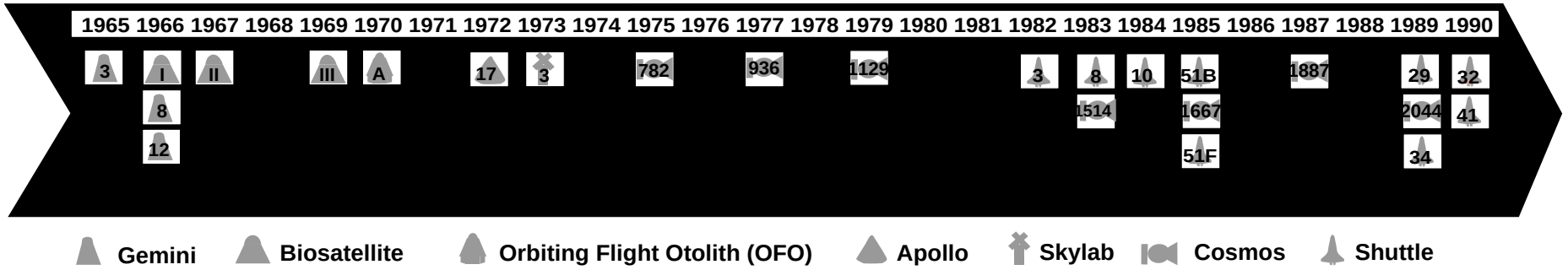


Figure 4-2: Flight experiments timeline.

Organisms Flown	Mission/Payload
Vertebrates: Adults or juveniles	
Rat (*Rattus norvegicus*)	Cosmos 782, 936, 1129, 1514, 1887, 2044; STS-8, STS-10 STS-51B, STS-29, STS-41
Rhesus monkey (*Macaca mulatta*)	Cosmos 1514, 1667, 1887, 2044
Pigtailed monkey (*Macaca nemestrina*)	Biosatellite III
Squirrel monkey (*Saimiri sciureus*)	STS-51B
Pocket mouse (*Perognathus longimembris*)	Apollo 17, Skylab 3
Bullfrog *(Rana catesbeiana)*	OFO-A
Vertebrates: Embryonic forms	
Frog (*Rana pipiens*) eggs	Gemini 8, Gemini 12, Biosatellite I,II
Walbaum fish (*Fundulus heteroclitus*) roe	Cosmos 782
Rat (*Rattus norvegicus*) fetus	Cosmos 1514
Japanese quail (*Coturnix coturnix*) eggs	Cosmos 1129
Invertebrates: Adults or juveniles	
Fruit fly (*Drosophila melanogaster*)	Biosatellite I,II, Cosmos 782, 936
Parasitic wasp (*Habrobracon juglandis*)	Biosatellite I,II

Organisms Flown	Mission/Payload
Invertebrates: Embryonic forms	
Fruit fly (*Drosophila melanogaster*) larvae	Biosatellite I,II, Skylab 3
Flour beetle (*Tribolium confusum*) pupae	Biosatellite I,II
Sea urchin (*Arbacia punctulata*) eggs	Gemini 3
Plants	
Pepper (*Capsicum annuum*) plant	Biosatellite I,II
Flowering *(Tradescantia)* plant	Biosatellite I,II
Wheat *(Triticum vulgare)* seedling	Biosatellite I,II
Carrot (*Daucus carota*) tissue and/or cell	Cosmos 782, 1129
Pine (*Pinus elliotti*) seedling	STS-3, STS-51F
Oat (*Avena sativa*) seedlings	STS-3, STS-51F
Mung bean (*Vigna radiata*) seedling	STS-3, STS-51F
Corn (*Zea mays*) seedling	STS-34
Unicellular forms	
Amoeba (*Pelomyxa carolinensis*)	Biosatellite I,II
Slime mold *(Neurospora crassa)*	Biosatellite I,II, STS-32
Bacteria *(Salmonella typhimurium)*	Biosatellite I,II
Bacteria *(Escherichia coli)*	Biosatellite I,II

Table 4-2: Organisms used in NASA Ames Research Center flight experiments.

flight. A chimpanzee, Ham, was sent into space in a Mercury capsule powered by a Red Stone booster before Commander Alan Sheppard's historic ballistic space flight in 1961. The capsule reached an altitude of 250 km over a range of 662 km. Electrocardiogram, respiratory waveform, and rectal temperature were recorded from the chimpanzee. Data was also collected on the performance of discrete and continuous avoidance tasks. The flight was important in demonstrating that a primate closely related to man could survive and perform critical tasks in space.

During the same year, an animal once again paved the way for man, when a male chimpanzee named Enos preceded astronaut John Glenn in orbital flight. The animal flew in a Mercury capsule powered by an Atlas missile, and spent a total of 183 minutes in a weightless environment. Electrocardiogram, body temperature, respiration, and psychomotor tests were monitored as in previous flights. A catheter was used to collect urine produced during the flight, and the animal was diapered for feces collection. Arterial and venous blood pressure was recorded via intravascular catheters. Blood pressure was shown to be high, probably because of the stress associated with instrumentation and flight.

The two chimpanzee flights verified the adequacy of the capsule environment control system for subsequent use on manned flights. The recoverability of the vehicles and the absence of adverse physiological reactions from short-term weightlessness were also demonstrated.

From 1960 to 1961, effects of microgravity and radiation were studied in human serum, rabbit antisera, plant seeds, viruses, bacteria and tissue cultures flown on the Discoverer satellites XVII, XVIII, and XXXII.

Payloads Since 1965

Twenty-five missions were developed by ARC between 1965 and 1990, using 25 different species (Tables 4-1 and 4-2). Each mission is described separately in the subsequent sections of this chapter.

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Gemini Program

Program Overview

The one-man Mercury spacecraft that were launched between 1961 and 1963 did not provide sufficient space flight experience for the great endeavor that was to be the Apollo program. It was within the Gemini program that a large part of this experience was gained. The Gemini program's primary objective was to demonstrate long duration flight, orbital maneuvers, guided spacecraft re-entry, and space rendezvous and docking. The success of the Apollo program's lunar landing objectives depended on mastery of these techniques.

The first two Gemini missions were unmanned tests of spacecraft systems. During a 20-month period between 1965 and 1966, 10 manned missions were flown, each with a crew of 2 men. During the last five missions, the Gemini spacecraft met up with Agena rockets that were placed in orbit as docking targets. The need to rendezvous with orbiting targets meant that launch windows were fre-

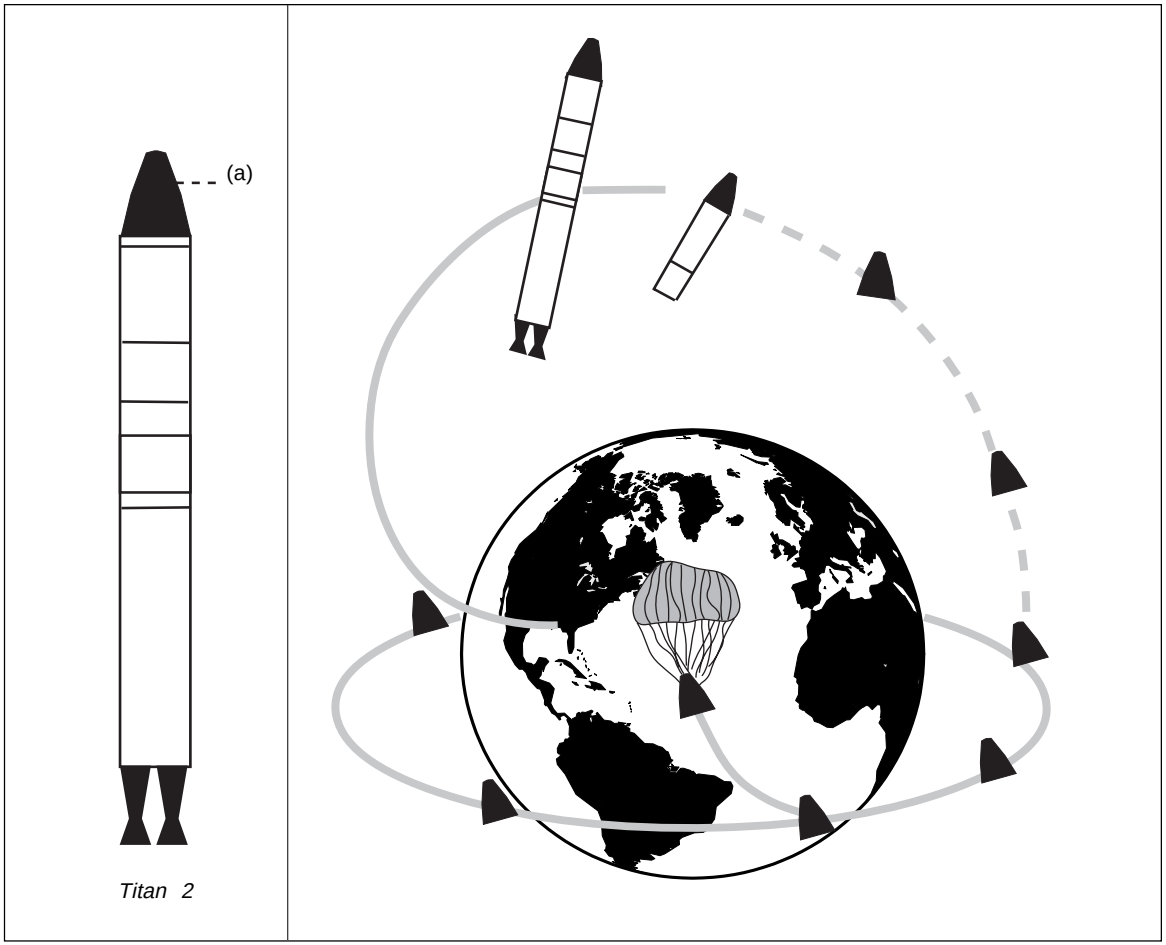

Figure 4-3: Launch and recovery of Gemini missions; (a) Gemini capsule .

quently very short. Because of this constraint, the efficiency of ground operations improved dramatically during the Gemini era.

The Spacecraft

Although it was based on Mercury technology, the Gemini spacecraft required relatively sophisticated maneuvering capabilities because they had to dock with a rocket in orbit. Onboard computers were needed for the same reason.

The 3.6 ton spacecraft was shaped like a truncated cone. Unfortunately, the crew capsule was quite cramped because there was only 50 percent more cabin space than in the Mercury capsule, for twice the number of crew members. Emergency crew ejection seats replaced the escape rocket tower that had been part of the Mercury spacecraft. The compartments containing fuel, water, and oxygen were designed to separate from the crew capsule before landing.

Small rocket engines were used to change the orbital path, and radar allowed the spacecraft to rendezvous with orbiting rockets. A fuel cell provided the electricity needed during long duration flights.

A large number of science experiments were carried out on the Gemini spacecraft. Three of these were life sciences investigations developed by ARC.

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MISSION PROFILE: Gemini 3

Mission Duration: 5 hours

Date: March 23, 1965

Life Sciences Research Objectives

To study the effect of microgravity on embryonic development

Life Sciences Investigations [p. 179]

Cell/Developmental Biology (G3-1)

Organisms Studied

*Arbacia punctulata (*sea urchin) eggs

Flight Hardware [pp. 550-551]

Sea Urchin Egg Package

Publications [p. 395]

Gemini 3

The Gemini 3 spacecraft was launched on March 23, 1965. Its commander nicknamed it "Molly Brown" after the Broadway hit "The Unsinkable Molly Brown." The mission was the first manned flight in the Gemini Program. The primary task of the two crew members was to test the new spacecraft's maneuverability. Changing orbital paths had not been possible in spacecraft used in earlier orbital flights.

Three orbits were completed before the Gemini 3 mission was terminated. Although the spacecraft had been designed for a precision landing, splashdown occurred some 80 km away from the targeted landing site.

ARC flew one life sciences experiment on the mission, which was unsuccessful because of a hardware failure.

Life Sciences Objectives

The objective of the life sciences experiment was to investigate the effects of microgravity on fertilization, cell division, differentiation, and growth in a simple biological system.

Life Sciences Payload

Organisms

The experimental specimens were eggs of the sea urchin *Arbacia punctulata*.

Hardware

Eggs were flown in eight specimen chambers. Each chamber was divided into three compartments, containing either sperm, ova, or fixative. Eggs could be fertilized, or fertilized eggs could be fixed, when the contents of the compartments were mixed by manually rotating a handle.

A ground control experiment was carried out in eight identical chambers, following the same procedures as in flight.

Operations

Eggs in four of the flight chambers were fertilized just before launch. The crew members were to fertilize the eggs in the other four chambers shortly after the spacecraft was inserted into orbit. The fixative in the third compartment of each chamber was to be added to the fertilized eggs at five different times during the flight. This would enable the development of the sea urchin embryos to be arrested at specific stages. Cabin temperature and time were to be recorded each time a crew member manipulated the experimental package.

Unfortunately, the handle on the hardware unit that activated either fertilization or fixation broke before any of the in-flight operations could be carried out. Toxicity of hardware materials may also have been a problem.

Results

The objectives of the experiment were not achieved because of the hardware malfunction.

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MISSION PROFILE: Gemini 8

Mission Duration: 11 hours

Date: March 16, 1966

Life Sciences Research Objectives

To study development in fertilized frog egg

Life Sciences Investigations [p. 180]

Cell/Developmental Biology (G8-1)

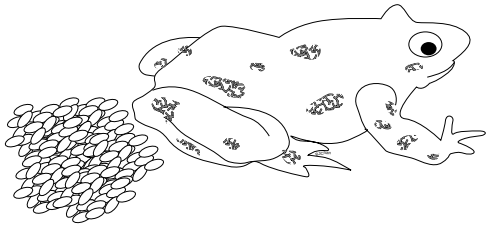
Organisms Studied

Rana pipiens (frog) eggs

Flight Hardware [pp. 538-539]

Rana (frog) Egg Package

Publications [p. 395]



Gemini 8

The eighth flight in the Gemini series of missions was launched on March 16, 1966. A stuck thruster on the spacecraft necessitated an emergency return to Earth a little more than 10 hours after launch.

The first orbital docking in the history of space flight was achieved on the mission, when the Gemini 8 spacecraft docked with a pre-launched Agena rocket.

The scientific payload on the spacecraft included an experiment using frog eggs.

Life Sciences Objectives

The objective of the experiment was to study the effects of microgravity on development in a gravity-oriented biological system.

Life Sciences Payload

Organisms

Fertilized eggs of the bullfrog *Rana pipiens* were used in the experiment.

Hardware

There were two experiment packages mounted on the sill structures of the spacecraft hatch. Each package contained four two-celled chambers. One cell in each chamber had five frog eggs in spring water, the other cell had a formalin fixative. Each experiment package included a handle that could be manipulated to allow fixative to flow into the egg compartments. Activating fixation at

different times during the flight would allow eggs to be preserved at various stages of development. The packages also had temperature control systems that maintained the temperature between 66°F and 74°F during the flight.

Operations

Two ground control studies were performed. One was carried out at the same time as the flight experiment. Actual flight temperatures were duplicated in the other ground control study, which was begun two hours after launch. The delay was necessary because flight temperatures could not be continuously telemetered to the ground.

Ovulation was induced in several female frogs by injecting them with frog pituitary gland extract about two days before launch. Selected eggs were fertilized with a sperm suspension and kept at 6°C in the experiment packages until launch.

A crew member activated egg fixation in one of the chambers 40 minutes after launch, and in another 15 minutes later. Eggs in two chambers were to be fixed 130 minutes after launch, and in two others shortly before re-entry. These procedures could not be completed because an emergency landing had to be made.

Results

No conclusive results were obtained because the mission had to be terminated prematurely. Only embryos arrested at an early developmental stage were obtained; these were normal. Thus, a gravitational field did not appear to be necessary for eggs to divide normally. However, it should be noted that fertilization occurred on the ground, and that the eggs were exposed to microgravity only after the two-cell stage. Ground-based studies have shown that this stage is critical to normal development.

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MISSION PROFILE: Gemini 12

Mission Duration: 4 days

Date: November 11–15, 1966

Life Sciences Research Objectives

To study development in fertilized frog eggs

Life Sciences Investigations [p.181]

Cell/Developmental Biology (G12-1)

Organisms Studied

Rana pipiens (frog) eggs

Flight Hardware [pp.538-539]

Rana (frog) Experiment Package

Publications [pp.395-396]

Gemini 12

The four-day Gemini 12 mission was launched on November 11, 1966. Only one biological experiment was performed onboard the spacecraft. It was a reflight of an experiment that had flown on the Gemini 8 mission. The results of the Gemini 8 experiment were inconclusive because the mission had to be terminated prematurely.

Life Sciences Objectives

The objective of the experiment was to study the effect of microgravity on developmental processes.

Life Sciences Payload

Organisms

Eggs of the bullfrog *Rana pipiens* were used in the experiment.

Hardware

The hardware used was identical to that used in the experiment on Gemini 8, except that there was only one unit on this mission. The unit was mounted on the pilot's hatch.

Operations

Control studies and preflight procedures were similar to those performed for the Gemini 8 experiment.

Fixative was released into individual egg chambers 40 minutes and 130 minutes after launch. Eggs in a third chamber were fixed

shortly before re-entry. The eggs in the fourth chamber were left alive for comparison with the fixed specimens.

The experiment equipment and specimens were removed from the spacecraft shortly after recovery.

Results

Development was normal, indicating that a gravitational field was not necessary for eggs to divide normally or to develop at later stages. However, as in the Gemini 8 mission, the eggs were fertilized on the ground and exposure to microgravity occurred only after the two-cell stage, which is thought to be critical for normal development.

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U.S. Biosatellite Program

The Biosatellite program was the first major effort by the U.S. to exploit Earth-orbital missions to study basic biological processes in space. Biological experiments had been previously flown somewhat informally on balloons and orbiting vehicles designed for other purposes. Since controls were usually inadequate on these flights, it was difficult to specify causes for effects observed in biological specimens after space flight. It was only with the advent of this program that missions devoted exclusively to carefully controlled biological experimentation were launched in unmanned Earth-orbiting spacecraft.

Program Overview

When the Biosatellite program was first initiated, NASA received more than 200 proposals for experiments to be conducted on the spacecraft. Thirteen of these experiments were selected for the first flight. The intention was to study the broadest range of space flight effects on biological systems. Three missions were originally proposed, with flight durations of 3, 21, and 30 days. Because the first mission (Biosatellite I) was unsuccessful, a second three-day mission (Biosatellite II) was flown with replicas of the experiments onboard Biosatellite I. A 21-day rodent mission was never developed because of growing project costs. The third and final mission in the series, Biosatellite III, was planned as a 30-day primate flight.

Implementing the Biosatellite program required enormous resources for hardware and experiment development, operations, planning and management. For instance, some 1400 individuals

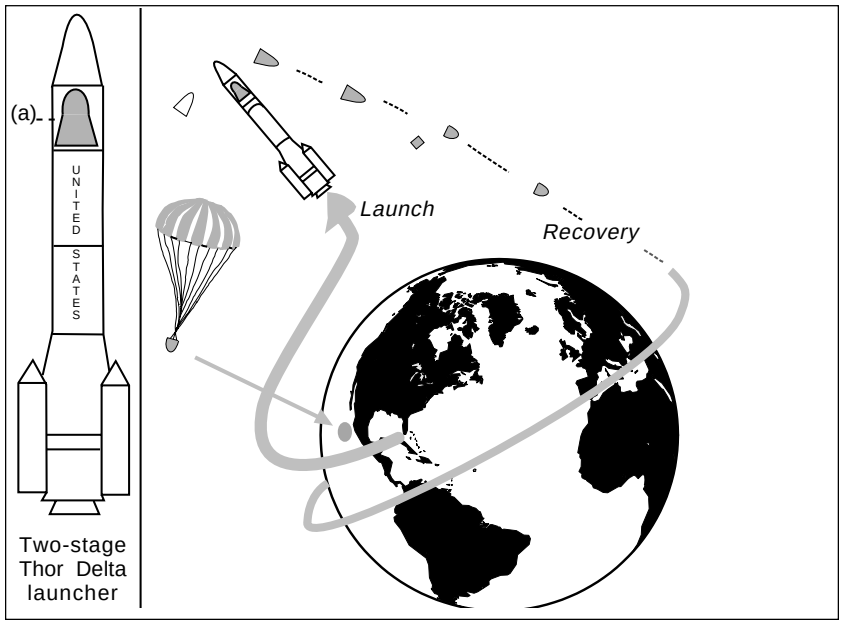

Figure 4-4: Launch and recovery of Biosatellite missions; (a) Biosatellite capsule.

cooperated in the complex Biosatellite II mission: 20 scientists and 120 technicians from universities, industry, and government laboratories participated directly in the mission; 770 contractor personnel were involved in designing, fabricating, and testing equipment and supporting flight operations; 180 foreign nationals helped to track the biosatellite; more than 200 Navy and Air Force personnel were needed to safely recover the satellite; and about 200 NASA personnel were engaged in various mission activities.

Joseph Saunders

Joseph Saunders first became involved with the Biosatellite program while serving as head of the Medicine and Dentistry Branch at the Office of Naval Research. During his tenure with NASA from 1964 to 1973, Saunders served successively as Chief of Environmental Biology, Biosatellite Program Scientist, and Chief of Biology Programs in the Office of Manned Space Flight. From 1973 to 1983, he was the Deputy Associate Director for International Affairs at the National Cancer Institute, National Institutes of Health. Since then, he served the American Physiological Society as Manager of the Membership and Scientific Programs Department. He was also the Executive Director Emeritus of the American Association of Immunologists (AAI) and active in the AAI from 1986 to 1992.

When Saunders transferred to NASA in 1964, the experiments for the Biosatellite program had already been selected. Saunders credited Orr Reynolds, then Director of Biosciences Programs, with putting the program together. "Orr was a brilliant individual. People were amazed at his ability to act so well in a dual capacity as a scientist and a manager."

At one time, three missions had been planned in the Biosatellite program: a 3-day mission, a 21-day mission, and a 30-day primate mission. The 21-day mission that was to have succeeded Biosatellite II was canceled in favor of bringing forward the primate flight. Because of the imminent Apollo manned missions, there was considerable interest in collecting information on animal subsystems. Saunders agreed with the general consensus about the Biosatellite III mission. "The primate was over-invaded," he said. "A testicular biopsy was done just hours before the flight, and who even knew if the animal would heal properly? In addition there was a catheter implanted in the animal's bladder, and other cardiovascular implants." He believed in the importance of educating people about the research that was done, so that they would be able to approach problems without repeating the mistakes of the past.

According to Saunders, one of the biggest problems in the Biosatellite program was the lack of communication between the biologists and engineers in developing the flight hardware. He cited the example of the frog egg experiment, which was carried out in four egg modules. "The first module was beautiful, it worked real well. In the second module, the frog eggs died, but not all of them. In the third module, 75 percent were dead. When we opened the fourth module, we didn't know what had happened. The eggs were all dead." The enigma was finally solved, as Saunders explained: "The modules had been machined out of lucite. You had to clean these things once you got them engineered. Well, we specified 20 washes. But the water simply wasn't changed each time a module was run through. So every module went through the same water. The first module was fine just because there were no pollutants, no residual plastic in the water."

When it comes to future space flight research, Saunders stressed the importance of plant experiments. "Based on my experience with Biosatellite II, my feeling is that a lot of the significant science information came from those plant experiments. To survive in space for long periods, you are going to need palatable and nutritious foods. We can't compress everything into pills at this time, and even if we could, who would want to live on that for a long time?" He was optimistic about NASA's plans for a space station. "I may not be around to see it. Our grandchildren may not be around to see it. But I think that ultimately space is going to be our future."

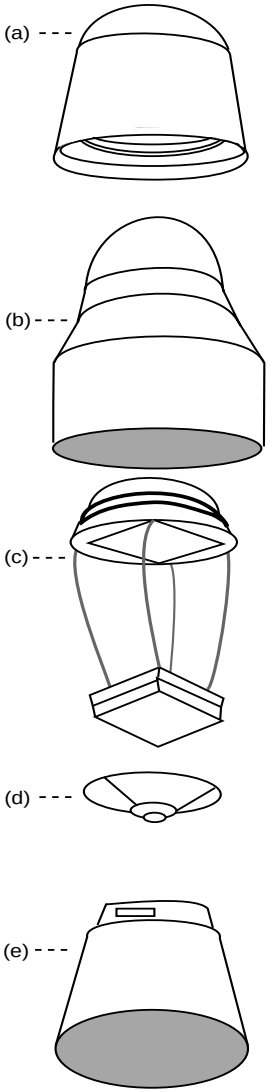

Figure 4-5: The Biosatellite spacecraft components:
(a) re-entry shield for thermal protection; (b) capsule assembly for holding the biological materials; (c) parachute assembly for slowing spacecraft descent; (d) thrust cone assembly for slowing and maintaining orientation of the re-entry vehicle during re-entry; (e) adapter assembly for attitude and position control.

The Spacecraft

The Biosatellite spacecraft was designed to accommodate the primary requirement for an automated laboratory suitable for biological experimentation in a weightless environment (Fig. 4-5). To fulfill this requirement, the experiments had to be protected from the external environment and be maintained in a controlled internal environment. A battery-powered model with bottled air was developed for the initial three-day flight. The 30-day flight model featured a fuel cell and carbon dioxide removal.

The 8-ft long spacecraft was 4.5 ft in diameter at its widest point. The re-entry vehicle, which separated and returned to Earth at the end of the flight, contained approximately the spacecraft's half weight and bulk. The smooth external surface permitted maintenance of moderate internal temperatures, with a minimum of electrical heating. Gyroscopes were used to sense angular rates of the spacecraft and compressed nitrogen gas was used to reduce rotation rate to less than 1 revolution in 20 minutes. The biological specimens were thus exposed to acceptably small acceleration forces.

The re-entry vehicle consisted of the experiment capsule, the heat shield, and the thrust cone or retro-rocket assembly. The aluminum experiment capsule contained the experiments and all equipment necessary to provide the desired environment for the experiments. A timer set during flight initiated the separation and recovery systems from the ground. The spacecraft oriented itself for retrofire relative to the local horizon and the local geomagnetic field. After separating by explosively released springs, the re-entry vehicle was spun about its major axis to maintain orientation and slowed by firing the retro-rocket. Shallow-angle re-entry occurred about 4000 miles further down range. After ejection of the parachute cover, the re-entry heat shield fell away. During descent, hooks from a C-130 retrieval aircraft could be attached to the specially reinforced parachute. At separation, a radio-homing beacon was energized and a dye marker activated in the event that the capsule landed in the ocean.

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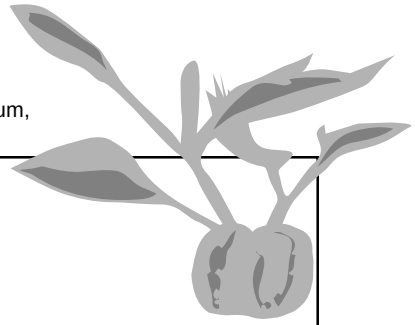
Biosatellite I and II



Capsicum annuum, *pepper plant*

MISSION PROFILE: Biosatellites I and II

Mission Duration: Biosatellite I—not recovered
Biosatellite II — 2 days

Dates: Biosatellite I — December 14, 1966
Biosatellite I/II— September 7–9, 1967

Life Sciences Research Objectives

To examine the influence of microgravity on the growth, form, development, morphology, and biochemistry of a selected group of organisms

To determine the sensitivity of organisms to ionizing radiation in microgravity

Assess readiness of spacecraft subsystems for longer duration flights

Life Sciences Investigations [pp.182-195]

Cell/Developmental Biology (BIO2-1, 5.1, 5.2, 6, 7, 8)
Plant Biology (BIO2-9, 10, 11, 12)
Radiation/Environmental Health (BIO2-2, 3, 4, 13)

Organisms Studied

Capsicum annuum (pepper) plants
Habrobracon juglandis (parasitic wasp)
Neurospora crassa (fungus) spores
Pelomyxa carolinensis (amoeba)
Rana pipiens (frog) eggs
Drosophila melanogaster (fruit fly) larvae and adults
Tradescantia (flowering plants)
Tribolium confusum (flour beetle) pupae
Triticum vulgare (wheat) seedlings
Salmonella typhimurium (bacteria)
Escherichia coli (bacteria)

Flight Hardware

Capsicum Experiment Package [pp.468-469]
Drosophila Experiment Package [pp.486-487]
Habrobracon Experiment Package [pp.494-495]
Lysogenic Bacteria Experiment Package [pp.496-497]
Neurospora Experiment Package [pp. 498-499]
Pelomyxa Experiment Package [pp. 502-503]
Radiation Source and Holder [pp.536-537]
Rana Experiment Package [pp. 538-539]
Tradescantia Experiment Package [pp.556-557]
Tribolium Experiment Package [pp.558-559]
Triticum Experiment Package [pp.560-561]

Publications [pp.396-402]

The first mission in the Biosatellite series, Biosatellite I, was launched in December 1966. Re-entry into the Earth's atmosphere was not achieved because the retro-rocket on the spacecraft failed to ignite. The biosatellite was never recovered. Although the scientific objectives of the mission were not accomplished, the Biosatellite I experience provided technical confidence in the program because of excellent performance in most other areas.

Improvements were made in hardware, prelaunch tests, and procedures before Biosatellite II was launched on September 7, 1967 from Cape Kennedy. The scientific payload, consisting of 13 select biology and radiation experiments, was exposed to microgravity during 45 hours of Earth-orbital flight. Experimental biology packages on the spacecraft contained a variety of specimens, including insects, frog eggs, microorganisms, and plants.

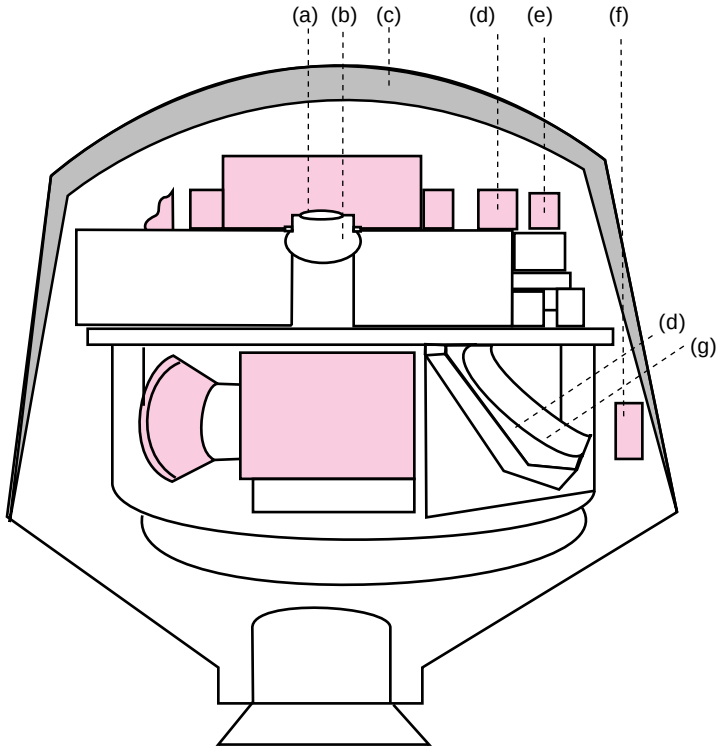


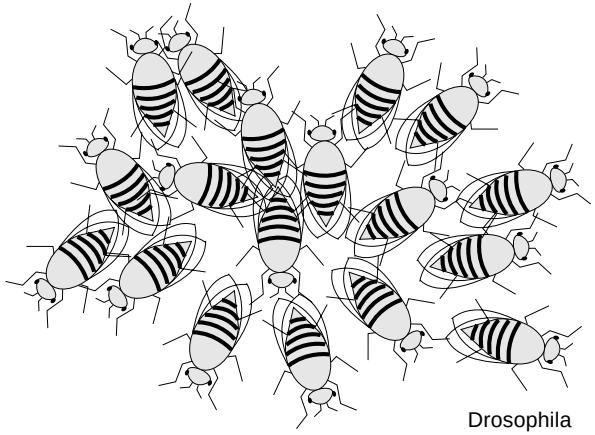
Figure 4-6: Cross section of spacecraft showing location of life sciences experiments in Biosatellite II: (a) radiation source; (b) radiation source holder; (c) heat shield; (d) experiment package; (e) backscatter field; (f) nuclear emulsion package; and (g) experiment package.

The planned three-day mission was recalled early because of the threat of a tropical storm in the recovery area, and because of a communication problem between the spacecraft and the tracking systems.

Life Sciences Research Objectives

The primary objective of the Biosatellite II mission was to determine if organisms were more, or less, sensitive to ionizing radiation in microgravity than on Earth. To study this question, an artificial source of radiation was supplied to a group of experiments mounted in the forward part of the spacecraft (Fig. 4-6).

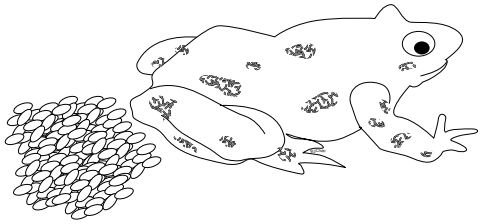
The shielded aft section of the spacecraft contained unirradiated controls and experiments. Experiments conducted onboard encompassed a wide range of disciplines and used several different species. A study on the effects of space flight on genetics was carried out using fruit flies as subjects. The combined effects of



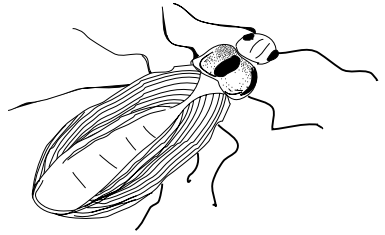
Drosophila melanogaster, *fruit fly*

microgravity and radiation were studied in fruit flies, wasps, fungi, and plants. Amoebae were used to investigate the nutrition and growth of cells in the weightless state. The developmental process was examined in frogs and beetles. Other experiments studied the effects of microgravity on plant growth and development, and on bacterial growth and phage induction.

The secondary objective of the mission was to assess the performance of spacecraft subsystems essential to the next planned mission, which was to be a 22-day orbital flight of a primate.



Rana pipiens *eggs, American leopard frog*



Tribolium confusum, *flour beetle*

Life Sciences Payload

Organisms

The general effects of space flight were studied in four different organisms: wheat seedlings grown in flight were examined for spatial orientation, morphogenesis, histochemistry, and biochemical changes; young plants of the Yolo Wonder bell pepper (*Capsicum annuum*) were studied for leaf orientation; development was studied in the eggs of the common American leopard frog *(Rana pipiens);* and giant multinucleate amoebae (*Pelomyxa carolinensis*, Pennsylvania strain) were flown for investigations on feeding, growth, and cellular structure.

Interactions between radiation and flight conditions were studied in adult parasitic wasps (*Habrobracon juglandis*), flour beetle (*Tribolium confusum*) pupae, larvae and adults of the fruit fly *(Drosophila melanogaster)*, lysogenic strains of bacteria *(Salmonella typhimurium* and *Escherichia coli)*, asexual spores of a fungus *(Neurospora crassa)* and bud-bearing plants (*Tradescantia)*.

Controls of several kinds were used to support the flight experiment. For the experiments on wheat seedlings and pepper plants, ground controls were conducted in the ordinary erect position and also rotated on horizontal clinostats. Standard ground controls were used in the other experiments. For the experiments involving radiation, unirradiated controls were flown in the aft section of the

spacecraft and both irradiated and unirradiated controls were maintained on the ground.

Ground controls were carried out at two different temperatures for most experiments. One set of controls was run at a constant temperature equal to or close to that set for flight. The other set of controls was run at temperatures that followed those recorded onboard the satellite and telemetered to Earth. This precaution, taken because an absolutely constant temperature could not be maintained onboard, proved to be valuable in interpreting data from several of the experiments.

Hardware

The forward payload included experiments exposed to an onboard radiation source. The aft payload included experiment packages identical to those in the forward payload, but which were shielded from the radiation source. Six additional experiments for studying the effects of microgravity alone were also included in the aft payload. A tungsten radiation source holder exposed the radiation source to the forward payload during specified segments of the mission. An equipment rack located between the forward and aft payloads contained power supplies and equipment required for experiment support and recovery operations. The interior of the capsule was maintained at the equivalent of a sea-level atmosphere on Earth, within limits specified by investigators. Total pressure and partial pressure of oxygen remained constant at 14.5 psia and 146 mm mercury respectively. Relative humidity and temperature were controlled according to specified limits.

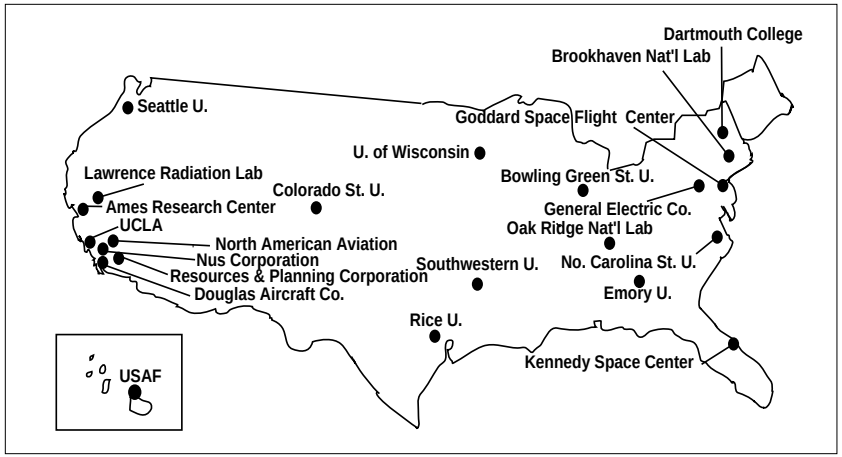


Figure 4-7: Biosatellite II participants.

The container for the *Drosophila larvae* consisted of several modules. Each module base was filled with melted culture medium before flight and a retaining sieve inserted. The larvae and live yeast were added to the module, the cover attached and the module inserted into the housing. Brackets were then placed over the eight modules in each housing. The container also had thermistors and lithium fluoride (LiF) radiation detectors.

Four identical packages were used for the *Tradescantia* experiment, two for flight and two for ground control studies. Each package held 32 plants with roots sealed in a tube containing a nutrient solution. Because the flower buds were arranged in a single row, they were uniformly exposed to gamma radiation. Small holes

in the cover of the package allowed air to enter, and a thermistor installed through the wall of the package registered temperature. Several passive dosimeters of LiF powder were placed in the root and bud zones of each package.

Neurospora packages were designed so that each of the samples within would receive a different total radiation exposure. Four packages were subjected to onboard radiation at different dosages. A fifth flight package was placed in the shielded aft section of the spacecraft. Five identical packages were used in ground control experiments. The package design allowed many *Neurospora* spores to be contained with minimal risk of contamination and anoxia. Each spore sample was placed on a moist Millipore filter. Filters were held in place on disks with polypropylene screens. Three independent dosimeters below each filter detected backscattered radiation. A module consisted of 10 disks stacked together with barriers between adjacent disks. Assembled modules were screwed into a housing unit to complete the package.

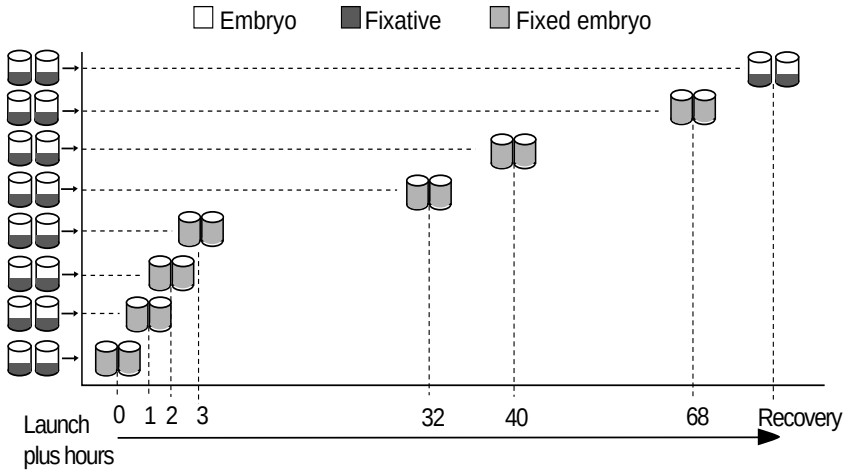


Figure 4-8: The frog embryology experiment on Biosatellite II had an automatic mechanism that fixed embryos at specific times during the flight so that embryos of varying ages could be studied postflight.

A plastic module with three compartments housed each group of *Tribolium pupae*. Each compartment contained an aluminum insert holding two felt layers sandwiched between tissue papers. One or two pupae were positioned in each of several holes punched in the pieces of felt. Four LiF dosimeters were inserted between two tissue papers with a layer of pupae on either side.

Five packages held the *Habrobracon* flown on the biosatellite. Four of these were exposed to varying degrees of radiation. One was placed in the shielded portion of the spacecraft. Each package contained four modules. *Habrobracon* were placed in depressions in each module. After a screen was placed over the depression, the module was capped and assembled into the flight package. Three glass rod dosimeters were included in each module. Additional dosimeters consisted of LiF powder in tubes placed in front of and behind the modules. Local temperature was recorded by a thermistor located centrally between the modules.

Two identical sets of four special packages were constructed to contain the lysogenic bacteria, one for the flight experiment and one for the ground-control experiment. One of the packages in each set contained 48 non-irradiated culture chambers. The other

3 packages each contained 16 growth chambers and were exposed to varying degrees of radiation.

Flight hardware for the frog embryology experiment was a package of eight pairs of modules. The design of the packages was that of the frog egg experiment packages on Gemini 8 and 12. Three similar hardware packages were used in ground-control experiments. A group of 10 fertilized eggs was placed in each of the first 8 modules. Groups of five were placed in each of the remaining modules. Each module was divided into two chambers: a 10 ml egg chamber and a fixative chamber. The O-ring-fitted piston separating the two chambers was spring-loaded and actuated in pairs of modules, by program or by command. Actuation effected forceful mixing of egg medium and fixative at different times during flight for seven of the module pairs (Fig. 4-8). This process enabled the investigators to obtain eggs fixed at varying times after fertilization. Live embryos were obtained from the last pair of modules. A coolant line around the hardware package maintained the experiment at 42.5°F on the launch pad. Four thermistors in the package registered temperature. A fifth thermistor switched off the strip heaters that raised package temperature to 70°F immediately after launch.

One flight and three control units contained amoebae and paramecia (Fig. 4-9). Each unit had 24 tripartite chambers. A piston with an O-ring separated the three segments of each chamber, which contained, respectively, amoebae, paramecia, and a fixative. Initial actuation of the piston resulted in mixing of amoebae and paramecia. Further actuation mixed the amoebae and paramecia

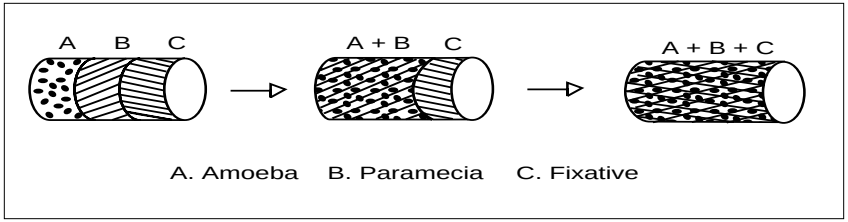
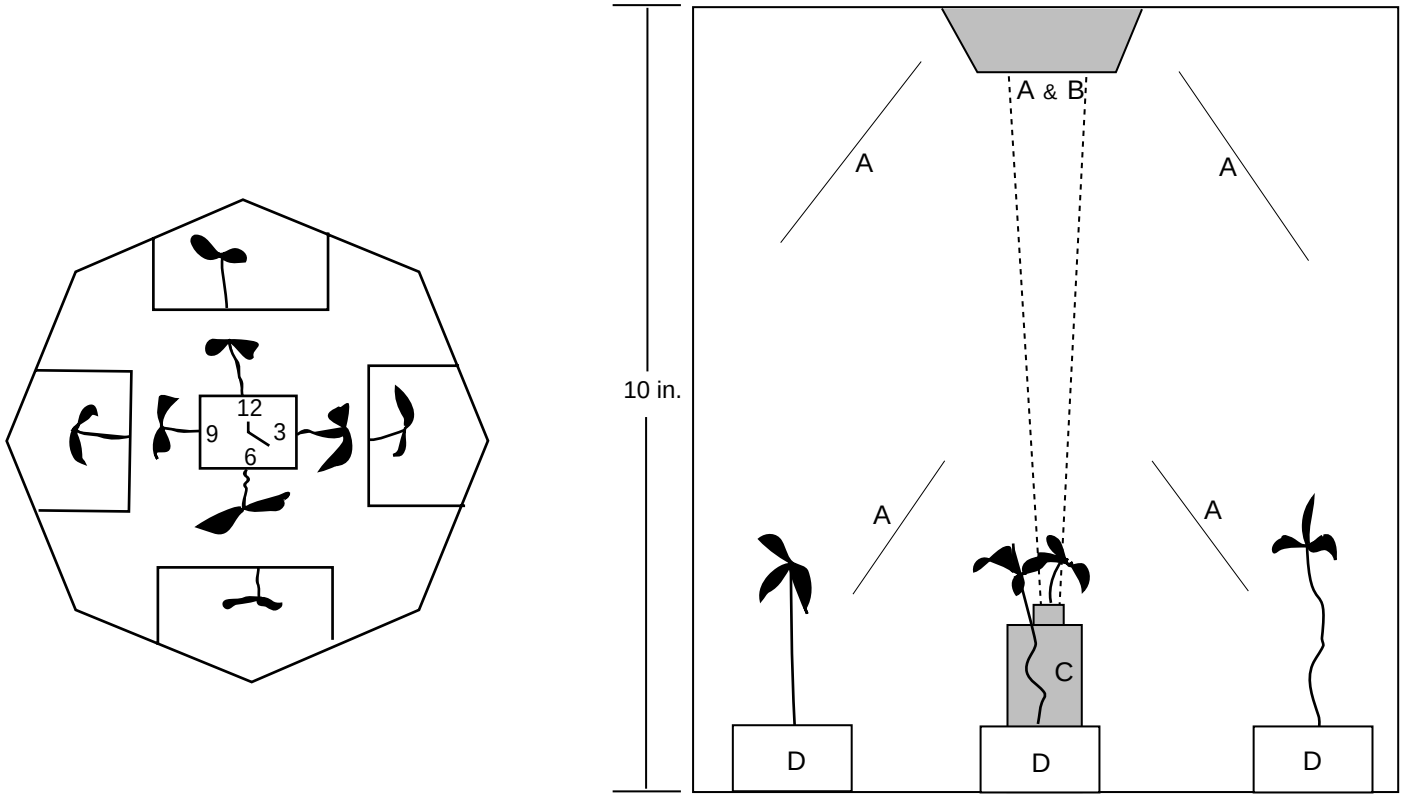


Figure 4-9: Biosatellite II amoebae were fed with paramecia when the contents of compartments A and B were mixed. Fed amoebae were fixed when the contents of compartment C were added.

with the fixative. Four of the chambers had thermistors for measuring in-flight temperatures. High-density foam pads placed between chambers reduced the vibrations during powered flight and reentry.

The flight hardware unit for the wheat seedling experiments held 78 wheat seeds. It had one large chamber and three small ones. In the large chamber, 12 seeds were inserted into each of 3 polycarbonate stalks containing wetted vermiculite. The remaining seeds were contained in the three smaller chambers. Two of these chambers were equipped to spray-fix the seedlings during orbit. The seeds germinated in darkness. Thermistor records of chamber temperatures were reported periodically to the ground stations. Four additional hardware units were used in ground control experiments.

For the pepper plant experiment, one plant was placed in each of four plant holders within the flight unit (Fig. 4-10). A three-mirror optical system and a camera allowed the top and sides of the plants to be photographed at 10-minute intervals during orbit. A



clock was inserted between the top central mirrors so that each frame of the film showed the position of leaves with respect to time. Four incandescent lamps illuminated the plants for 5 seconds every 10 minutes, and facilitated photography. The unit was covered

Figure 4-10: In the Biosatellite II pepper plant experiment, a camera recorded the positions of plant leaves with respect to time. A diagrammatic representation of the view seen through the camera (left). A side view showing experiment setup (right); A. mirror, B. clock, C. camera, D. plants.

with a white sleeve during flight to maximize light use and prevent light from leaking into the biosatellite capsule. Air exchange was permitted through a series of small holes in the sleeve. Five more plants placed inside the unit later provided samples for carbohydrate, amino acid, and nitrogen analysis. Three additional hardware units were used for ground control experiments.

Operations

The operations carried out to fulfill the needs of individual experiments were complex. The description below outlines the general operations performed to ensure successful launch and recovery of the biosatellite capsule.

Although the spacecraft was designed to be flown using existing space flight services, additional operational procedures were developed because it was imperative to safely recover the biological materials onboard. The compatibility of the spacecraft system with the existing Space Tracking and Data Acquisition Network (STADAN) was successfully demonstrated. Support was enlisted from various STADAN stations in North and South America and South Africa for the operational phase of the mission (Fig. 4-11). Several facilities at Goddard Space Flight Center and Cape Kennedy were modified to meet mission requirements. Training exercises were held in the Hawaiian Islands recovery area for both an air recovery and a backup water recovery. In addition, Air Force Rescue and Retrieval Service Forces in the Azores, Bermuda, Guam, and Japan were prepared to retrieve the capsule in the event of an emergency call-down. At Cape Kennedy, compatibility between the spacecraft and the Delta launch vehicle had to be ensured.

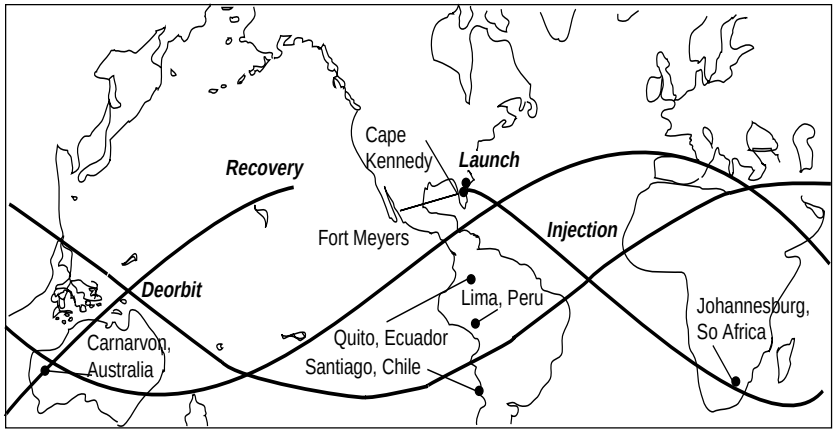


Figure 4.-11: STADAN stations involved in controlling the launch, injection into orbit, deorbit, and recovery of the Biosatellite II. The lines indicate the path traveled by the spacecraft.

The normal Delta prelaunch sequence was shortened significantly in order to preserve the integrity of the experiments on Biosatellite II (Fig. 4-12). Prelaunch activities had to be reduced or eliminated on Biosatellite II because biological materials could not be kept on the launch pad for longer than eight hours. The preparation of each experiment, the spacecraft experiment assembly, and the spacecraft launch vehicle assembly all required special detailed procedures. These procedures were strictly time-correlated with other activities such as the assembly of control experiments.

Only a few seconds after the launch phase of the mission began, it became evident that the spacecraft was having difficulty accepting Earth commands. The system operated effectively in spite of this problem. At the end of the first complete orbit, all programmed functions were satisfactorily confirmed: the radiation source holder had opened 1 hour after launch; the pepper plants were being photographed every 10 minutes; the frog egg assembly had been appropriately heated; the amoebae had been fed with paramecia or fixed; and a frog egg module had been injected with fixative.

Because of the impending threat of a tropical storm in the recovery area, it was decided to terminate the mission after 30 orbits instead of the planned 46. All the remaining experiment actuation commands were rescheduled and accomplished during the last five orbits. De-orbit telemetry recordings were made with the assistance of the Woomera Tracking Station in Australia.

The flight phase of the mission was successfully concluded with the de-orbit of the recovery capsule, deployment of the parachute system, and air recovery by the U.S. Air Force on the first attempt. The subsystems in the spacecraft's adapter, which remained in orbit, were evaluated until the battery life was expended after 62 orbits.

The 280-pound recovery capsule was returned to the temporary biological laboratories at Hickam Air Force Base in Hawaii for disassembly. Immediate inspection of the biological materials showed them to be in excellent condition.

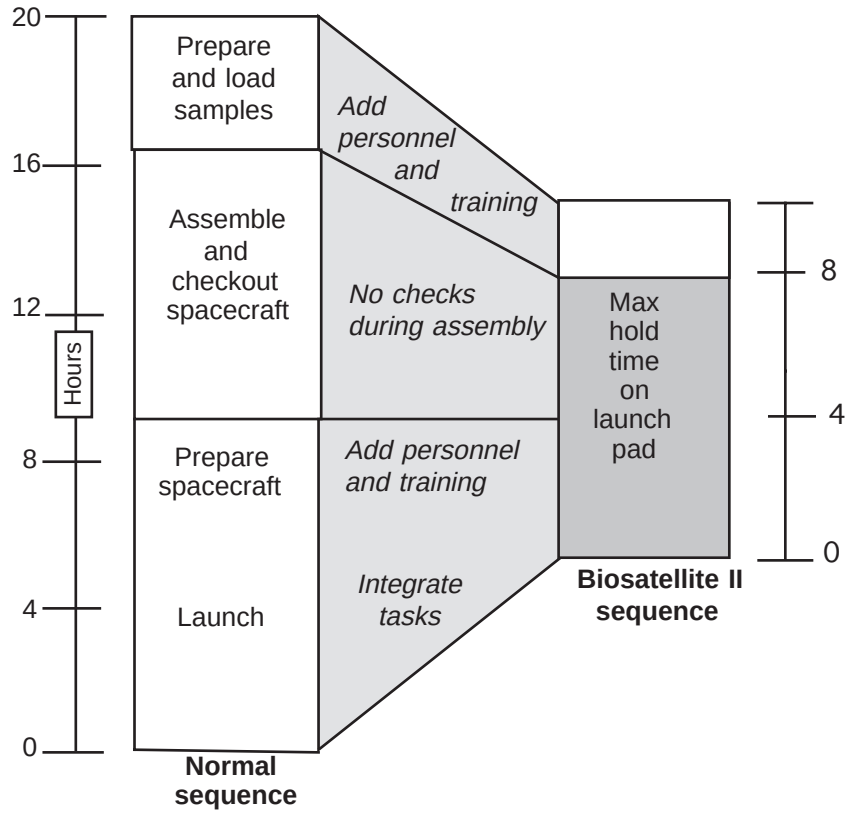


Figure 4-12: Modification of the prelaunch sequence to accommodate a biological payload.

Results

The Biosatellite II mission showed that it was feasible to operate an unmanned biology laboratory in the space environment. With very few exceptions, environment conditions imposed by experimenters were satisfied. Changes were noted in about 30 of the more than 100 biological parameters studied in the flight specimens. Radiation and flight conditions were found to interact, and, when nuclei were dividing, enhancement or synergism was found to occur in a number of different organisms. However, the relative roles of microgravity and vibration (alone or combined) as causes of this interaction were not determined.

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MISSION PROFILE: Biosatellite III

Mission Duration: 9 days

Date: June 28 – July 7, 1969

Life Sciences Research Objectives

To study space flight effects on brain states, behavior, fluid and electrolyte balance, metabolism, and the cardiovascular system

Life Sciences Investigations [pp.196-202]

Cardiovascular/Cardiopulmonary (BIO3-1)
Musculoskeletal (BIO3-2)
Neuroscience (BIO3-3.2)
Regulatory Physiology (BIO3-3.1, 3.3, 3.4, 4)

Organisms Studied

Macaca nemestrina (pigtailed macaque)

Flight Hardware [pp. 518-519, 508-517, 520-521]

Primate Physiological Sensors
Primate Life Support System
Primate Psychomotor Test System

Publications [pp. 402-404]

Biosatellite III

The last mission in the U.S. biosatellite program was Biosatellite III, launched on June 28, 1969. The intent had been to fly a pigtailed monkey in Earth-orbit for 30 days. However, after only 8.8 days in orbit, the mission was terminated because of the monkey's deteriorating health.

High development costs were a strong incentive for maximizing the scientific return from the mission. Because of this, the scientific goals had become exceedingly ambitious over time, and a great many measurements were conducted on the single research subject flown. Although the mission was highly successful from a technical standpoint, the science results were compromised, probably because too many bioinstruments were implanted in the monkey. Despite the failure of the mission's scientific agenda, Biosatellite III was enormously influential in shaping the life sciences flight experiment program, pointing to the need for centralized management, more realistic goals, and substantial preflight experiment verification testing.

Life Sciences Research Objectives

The mission objective was to investigate the effect of space flight on brain states, behavioral performance, cardiovascular status, fluid and electrolyte balance, and metabolic state. Radiation studies were also conducted.

Life Sciences Payload

Organisms

A single 6 kg male pigtailed monkey (*Macaca nemestrina*) named Bonnie served as the experimental subject on the mission (Fig. 4-13).

The animal was instrumented with sensors for 33 channels of physiological data. Implanted sensors included bipolar electroencephalographic electrodes, electrooculographic sensors, electromyographic leads, cardiovascular function and respiration sensors, and temperature sensors in the brain and peritoneal cavity. Catheters were chronically implanted in the saphenous vein and both femoral arteries to measure blood pressure, and in the bladder to collect urine. Four identically instrumented monkeys served as ground experiment controls.

Hardware

Equipment used for the flight experiment included bipolar electroencephalograph electrodes, electromyogram electrodes, electrooculogram electrodes, heart function and respiration sensors, four intravascular catheters to measure blood pressure, temperature sensors for the brain and peritoneal cavity, a urinary catheter, and transducers.

A psychomotor test system was used to obtain data on in-flight performance of visuomotor and delayed matching tasks. The animal was held in a hammock-style restraint system with a feces collector and attachments for the urine catheter and cardiovascular pressure monitoring and perfusion systems. Casein-based diet pellets from an electrically powered dispenser were provided during the flight. Twenty pellets were offered *gratis* every day. Another 40 pellets could be obtained each day as rewards for successful task completion. A suction-activated drinking system provided water. A seven-channel analog tape recorder was used to collect data.

An in-flight urine analyzer monitored the urinary excretion rates of calcium, creatine, and creatinine. Urine was passively transported into a container with a flexible diaphragm. A pump emptied the contents of the collector into a urine actuator once every hour. The actuator in turn delivered 10 ml volumes of urine to the analyzer. The analyzer consisted of a hermetically sealed case containing a urine sample accumulator, a calcium analyzer, a creatine-creatinine analyzer, reagent storage bags, logic sequencers, a data handling system, and a power converter.

Transducers within the spacecraft provided data on capsule total pressure, partial pressures of oxygen and carbon dioxide, air temperatures, pellets and water consumption, urine production, task performance, day and night light status, and changes in capsule attitude.

Operations

Surgeries were performed on the flight and control animals to implant the sensors described earlier. Other preflight surgical procedures included tail amputation, incisor tooth extraction, testicular biopsy, and anal suturing.

Although bioengineering tests of hardware with animal subjects were performed, no formal analyses of these test results are available in the literature. There is also no indication that a complete integrated flight duration test was ever successfully conducted.

While in orbit, the animal was exposed to a day and night cycle consisting of 12 hours of incandescent light and 12 hours of dim red light. The animal was presented with the opportunity to conduct psychomotor tasks at specific times during the light period. Successful task completion was rewarded with a limited number of food pellets. Additional food pellets were offered "free" during a specified period. Other periodic activities controlled automatically by the spacecraft clock included presentation of drinking water, time-lapse photography, and infusion of heparin, an anticoagulant, into the vascular catheters (Fig. 4-14). Accumulated urine was automatically analyzed for calcium, creatine and creatinine concentrations every six hours, and the results were telemetered to the ground.

The food and water dispensers and all monitoring systems operated well during the flight. However, the psychomotor test system provided no useful data because of the primate's inconsistent performance. The primate began to deteriorate between the fourth and eighth day of flight, ceasing to eat or drink, and becoming hypothermic and hypotensive. The environmental control system maintained ambient temperature at the minimum setting of 20.7°C throughout the flight. This may have contributed to the hypothermia noted in the flight animal.

When it became evident that the primate's condition was continuing to decline, the biosatellite was recalled. Immediately after the biosatellite was recovered, attempts were made to revive the primate but there was no response to remedial measures.

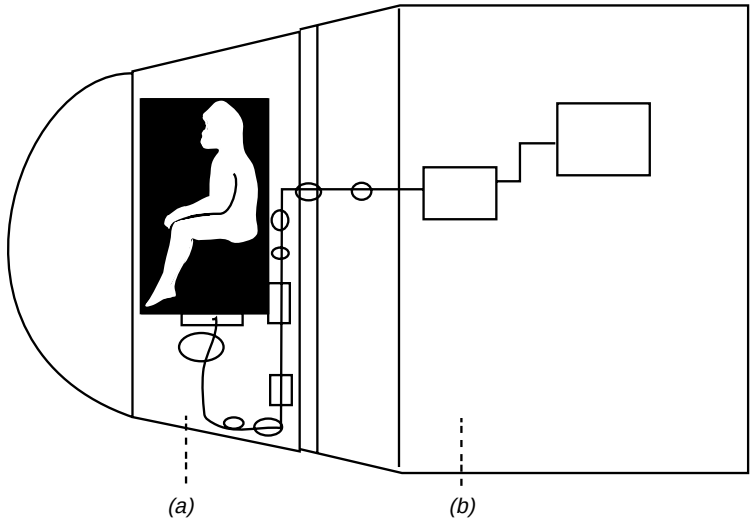

Figure 4-13: Location of the monkey on the Biosatellite III spacecraft. (a) The recovery capsule housed the monkey and life support and measurement systems. (b) The adapter section, containing a urine storage tank and urine analyzer, separated from the recovery capsule before it reentered Earth's atmosphere.

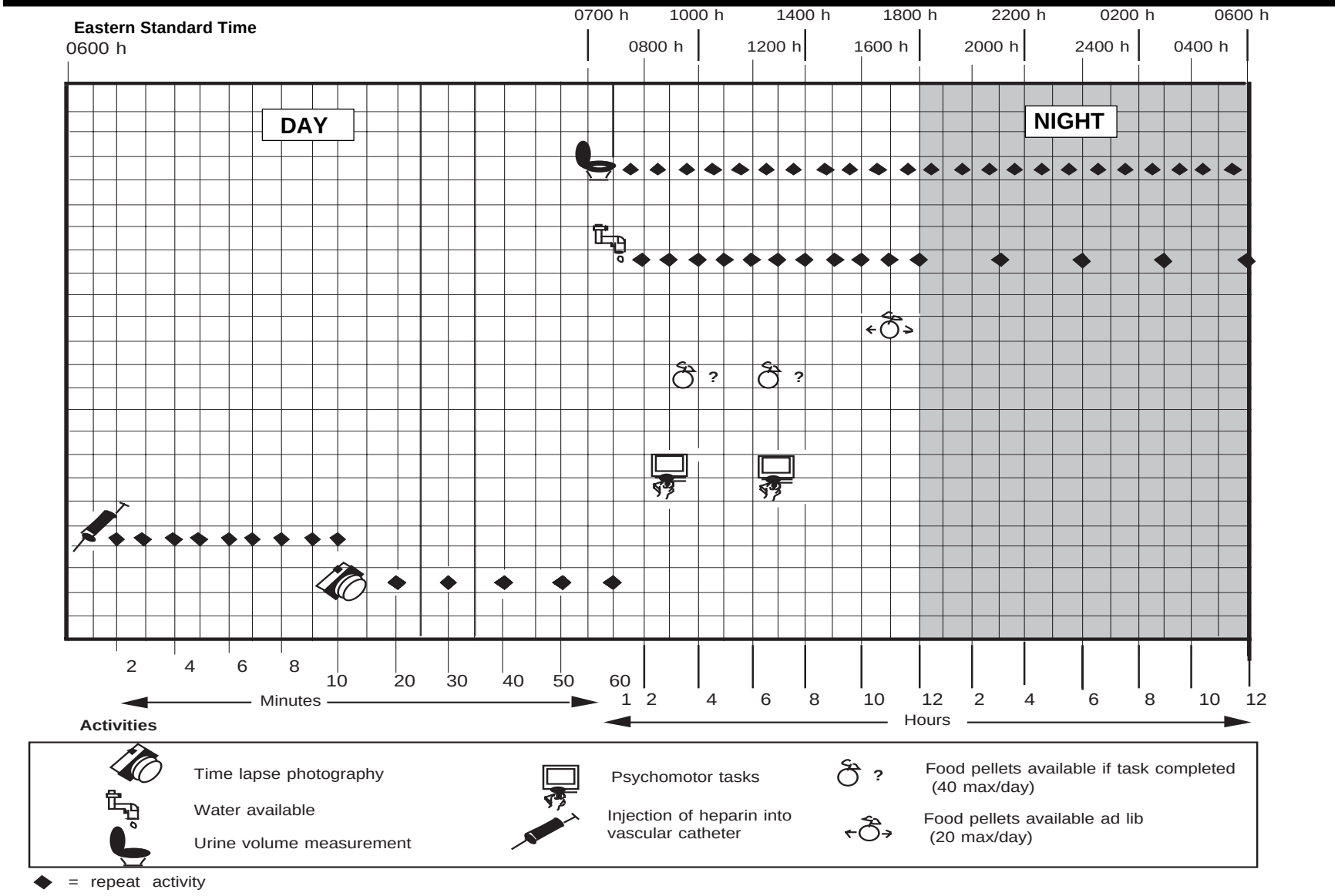

Figure 4-14: Daily in-flight activities on Biosatellite III.

Harold Klein

Harold Klein, a specialist in microbial physiology, served as Assistant Director for Life Sciences at ARC from 1964 to 1968, and Director of Life Sciences from 1968 to 1984. He is now Scientist-in-Residence at Santa Clara University, California, and a research scientist at the Search for Extraterrestrial Intelligence (SETI) Institute in Mountain View, California.

During the 1970s and 1980s, life sciences research at ARC was concentrated in three major areas. Aeronautical research focused on the behavioral aspects of aviation and on man-machine integration. Space biology and medicine research covered studies ranging from smaller organisms to human physiology. Exobiology research focused on investigating the prospects for life in the universe. "All three areas were constant themes throughout this whole period," Klein says.

Although animal experiments were conducted on the ground by the life sciences group at ARC to study the effects of hypergravity and radiation, space flight experiments were not conducted until the early 1970s. Until then, the group was mainly concerned with basic research rather than space flight experiment development. Because of this, the life sciences research agenda was not affected by the failure of the Biosatellite III mission, despite the fact that a good deal of adverse public attention was directed at ARC after the mission. "You have to understand the organization at Ames during the period when the biosatellites were flown," Klein explains. "There was a separate organization for biosatellite missions, basically dealing with engineering and management areas. They managed all the flight experiments from ARC, whether they were life sciences experiments or astrophysics experiments. So the life sciences group had no direct responsibility for the Biosatellite program." Klein and his colleagues were interested in the Biosatellite program, but somewhat pessimistic with regard to the Biosatellite III outcome since "there was only a single animal, very heavily instrumented..., and likely to be stressed to a degree that would make it difficult to dissociate any weightlessness or space-related effects."

Klein was involved with the joint U.S./Soviet activities on the Cosmos project from the very beginning of cooperation in the early 1970s. He recalls that the first time the two sides interacted in the area of space biology was in 1971, when the newly formed Joint Working Group for Space Biology and Medicine met for the first time. "Most of the discussion at the time centered around biomedical and life support issues. But I had some informal conversations with Gazenko (see p. 148) and Genin about what they were investigating with lower organisms. I think the seeds for what was to become the Cosmos interaction were sowed at that time. If we had not gotten along so well then, there would have been nothing." By 1974, the plans for cooperation had solidified into an invitation to the U.S. from the Soviet Union to participate in the Cosmos program. "At first, we didn't know there would be a continuing series of Cosmos flights on which we could participate. We were just invited onto one flight. The Soviets probably wanted to see how things would go from their side. Since the first time worked out well and the results were interesting, they invited us onto the next flight two years later." Klein describes the first U.S. experiments on Cosmos as being very simple. "They were not anything like the later experiments. There were no announcements of opportunity, no big peer reviews. We just did them because the spacecraft was available, specimens were going to be available, and we saw a chance to get some work done."

Nello Pace

Nello Pace served as the Director of the Environmental Physiology Laboratory in Berkeley from the 1960s to the mid-1980s. He is now an Emeritus Professor of Physiology at the University of California, Berkeley. He is the cofounder of the International Union of Physiological Sciences Commission on Gravitational Physiology and of the Galileo Foundation, dedicated to the support of gravitational physiology research.

As Director of the Environmental Physiology Laboratory in Berkeley, Pace received several NASA grants to conduct primate physiology research projects. One was a study of primate calcium balance during space flight conducted on the Biosatellite III mission.

Pace's team had originally intended to design a unit that would collect urine samples at intervals during the mission. They had planned to analyze the samples after the biosatellite was recovered. Then they heard about a miniaturized soil analyzer being developed by the NASA Jet Propulsion Laboratory (JPL) for the Viking Mars missions. They approached JPL about the possibility of conducting a joint venture. JPL was very interested because this would allow a flight test of the analyzer before the Mars missions. The JPL device was converted into a urine analyzer that allowed collected urine to be automatically analyzed while the spacecraft was still in orbit, rather than postflight. The resulting data could be downlinked to the ground, and summary data could be stored in the spacecraft's recovery capsule. Pace describes the urine analyzer as a remarkable piece of work. It worked flawlessly during the mission. There were many such engineering successes on the mission, but these were eclipsed by the furor over the death of the monkey subject.

According to Pace, the Biosatellite III experience strongly influenced the primate research program at NASA. Pace had proposed the Automated Primate Research Lab (APRL) in 1968, one year before the Biosatellite III flight. The objective of the project was to fly two adult pigtailed monkeys in Earth-orbit for 60 days. APRL was an offshoot of the Primate Hemodynamics and Metabolism on an Orbiting Satellite (PHAMOS) program, begun in 1958, which was one of the very first projects to come out of NASA. APRL never progressed to a flight stage because there was heavy opposition to flying primates in the aftermath of Biosatellite III. But several other programs and concepts grew out of it. Researchers became interested in ways of shrinking the "envelope" around the animal to protect it during space flight. Pace's team developed a "monkey pod," an enclosure that could safely house a restrained pigtailed monkey. The monkey pod was one of the primate experiments on NASA's SMD III, a Spacelab flight simulation test. It was proposed that the monkey pod be flown in the Shuttle middeck in the mid-1980s. This project was never completed, although several of its elements were incorporated into later primate flight programs.

French and Russian teams visited Pace's laboratory in the early 1970s to study the monkey pod system. Their willingness to fly primates in space increased as a consequence of these visits. It had long been known that many experiment results could only be extrapolated to humans if primates were flown. But until that time, both the French and the Soviets had not thought it possible to maintain a primate in comfortable restraint for long time periods.

Results

The flight subject died about eight hours after the capsule was recovered. The acute cause of death was ventricular fibrillation. At the time of death, body weight was 4.4 kg. Weight loss may have been due to the marginally palatable food pellets that had to be used to accommodate experimental requirements. Marked dehydration was evident. The cause of death is still controversial. At the time it was speculated that the changes noted in the animal were an effect of microgravity alone. However, subsequent Soviet and U.S. flights of monkeys, lasting from 5 to 14 days, have cast serious doubts on such a hypothesis. It is likely that over-instrumentation and chronic restraint resulted in the animal's demise. This possibility is supported by the deaths, shortly after the termination of the flight phase of the mission, of two of the similarly-instrumented ground-based controls.

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Orbiting Frog Otolith Program

The Orbiting Frog Otolith (OFO) Program was a part of the research program of NASA's Office of Advanced Research and Technology (OART). One of the goals of the OART was to study vestibular organ function in space and on the Earth.

Man's ability to orient himself with respect to his environment and his ability to coordinate his bodily movements has evolved in the constant presence of gravity. Because of this, it was difficult to predict how astronauts would respond to extended stays in microgravity.

The OFO experiment was designed to allow researchers to collect neurophysiological data on the response of the otolith to prolonged periods of weightlessness. The otolith is a part of the inner ear that is associated with equilibrium control: acceleration with respect to gravity as its primary sensory input.

After the successful OFO-A mission in 1970, interest in the research continued. A project called Vestibular Function Research was initiated in 1975 to fly a vestibular experiment in an Earth-orbiting spacecraft. This flight project was eventually discontinued, but a number of ground studies were conducted. The research has given rise to several very useful offshoots, including the ground-based Vestibular Research Facility located at ARC.

The OFO Spacecraft

The OFO experiment was originally designed for flight within the Apollo Applications Program, which was established to make optimum use of hardware used in Apollo lunar missions. However, because the low acceleration levels needed for the experiment could not easily be maintained in a manned Apollo spacecraft, an unmanned satellite was later chosen as a more suitable vehicle. The satellite's design eliminated exposures to acceleration levels above 10^{-3}g. This meant that the experimental specimens could experience an almost weightless state.

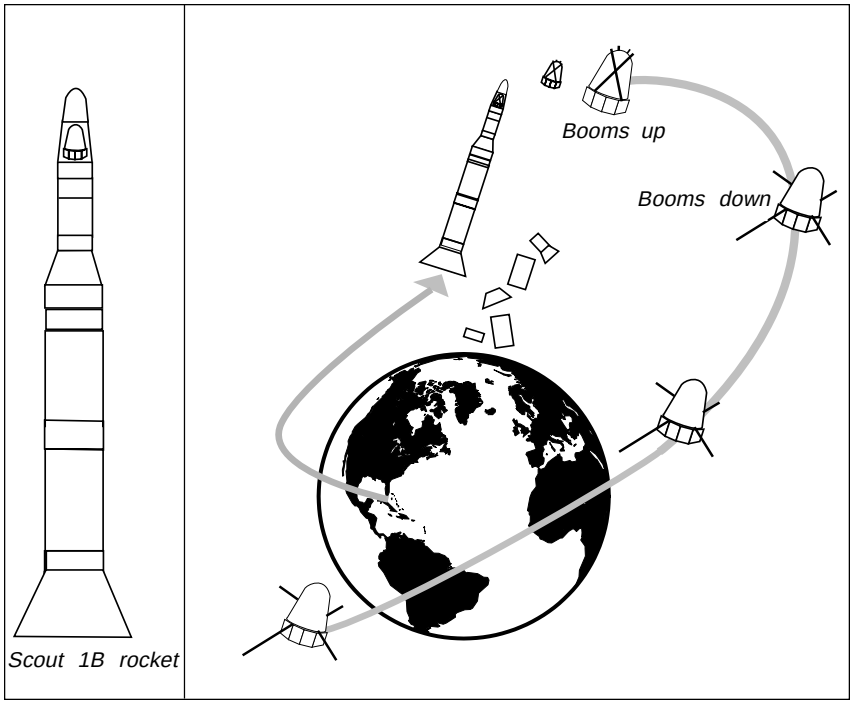

Figure 4-15: Launch of the Orbiting Frog Otolith (OFO) capsule (see also Fig. 4-16).

The spacecraft had a diameter of approximately 30 in. and a length of 47 in. The octagonal lower section of the spacecraft housed the electronic apparatus. The upper section, which contained the experiment package, was shaped like a truncated cone. A heat shield covering this upper section protected the experiment during re-entry into the Earth's atmosphere. A "yo-yo" despin assembly was located around the girth of the spacecraft. Four booms, folded against the side of the spacecraft, were located radially around the satellite. After the spacecraft separated from the launch vehicle, the yo-yo despin subsystem slowed spacecraft rotation. The four booms were then released to extend from the side of the spacecraft. The extension of the booms increased the moment of inertia of the spacecraft, permitting the acceleration level to remain below 10^{-3}g (Fig. 4-16).

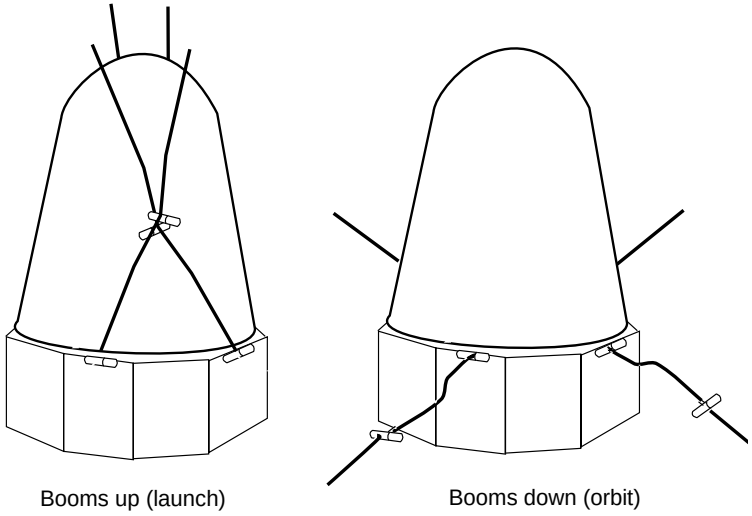

Figure 4-16: Orbiting Frog Otolith (OFO) with booms. Booms out increased the moment of inertia.

The spacecraft was launched by a Scout 1B rocket. The Scout 1B was a four-stage solid propellant rocket system, which was about 73 ft long and weighed about 40,000 pounds at lift-off. Also onboard was the Radiation Meteroid spacecraft to demonstrate and evaluate improved instrumentation and to gather near-Earth data of scientific interest.

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Space General Company. *Orbiting Frog Otolith Satellite (OFO) Mission Performance Report*. NASA CR-62083, December 1970.

MISSION PROFILE: OFO-A

Mission Duration: 6 days

Date: November 9–15, 1970 (not recovered)

Life Sciences Research Objectives

To study the effect of microgravity on the vestibular organ

Life Sciences Investigations [pp. 209-211]

Neuroscience (OFO-1.1, 1.2, 1.3)

Organisms Studied

Rana catesbeiana (bullfrog)

Flight Hardware [pp. 490-493]

Frog Otolith Experiment Package (FOEP)
FOEP Life Support System (LSS)

Publications [pp. 406-407]

Orbiting Frog Otolith-A

The OFO-A mission was launched on November 9, 1970. The satellite carrying the OFO-A experiment remained in orbit for almost seven days. Recovery of the spacecraft was not planned. The payload was the Frog Otolith Experiment Package (FOEP).

Life Sciences Research Objectives

The objective of the experiment was to investigate the effect of microgravity on the otolith, a sensory organ that responds to changes in an animal's orientation within the Earth's gravitational field.

Life Sciences Payload

Organisms

Two bullfrogs (*Rana catesbeiana*) were used as experimental subjects in the flight experiment. The bullfrog was chosen for study because its labyrinth is very similar to that of humans. Since it is an amphibian, preflight surgery could be performed above water, but it could be kept in water during the flight. The water medium served to cushion the vibration and acceleration of launch, and to facilitate gas exchange with the organisms.

Both flight frogs had electrocardiogram (ECG) electrodes implanted in their thoracic cavities and microelectrodes implanted in their vestibular nerves. The frogs were demotorized to prevent them from dislodging their implanted electrodes, and to reduce their metabolic rates. With this lowered metabolic activity, the frogs could survive in good health without being fed for as long as

one month. Immersion in water allowed the frogs to breathe through their skin. The water medium also helped to move carbon dioxide and heat away from the animals.

Hardware

The flight hardware unit, the FOEP, was a pressure-tight canister containing a water-filled centrifuge that housed the two frogs. The centrifuge was a cylindrical structure that rotated the frogs' heads at scheduled intervals. The FOEP also contained a life support system which could maintain a regulated environment for the frogs. This system consisted of two closed loops, one containing liquid and the other containing gas. The interface between the two loops was a selectively permeable silicone rubber membrane that acted as an artificial lung. Oxygen passed through the membrane from the gas to the liquid side, and carbon dioxide from the liquid to the gas side. The frogs were immersed in the liquid loop. A pump circulated oxygen through the gas-containing loop. Carbon dioxide entering the gas loop was removed by an absorbant and the purified oxygen returned to the pump for recirculation. A water evaporator and an electric heater maintained the water temperature at about 60°F. An amplifier system in the FOEP increased voltage output from the microelectrodes implanted in the animals to the level required by the telemetry apparatus.

Operations

Surgical preparation of the flight frogs was completed about 12 hours before launch, and the animals were sealed inside the FOEP. A backup FOEP was also prepared with similar specimens. The flight FOEP was installed in the satellite about three hours before launch.

The centrifuge was activated as soon as possible once the satellite was in orbit and stabilized at 10^{-3} g. The centrifuge applied gravity stimuli in cycles. Each cycle lasted about 8 minutes, and consisted of the following: a 1-minute period without acceleration, an 8-second period when rotation slowly began, 14 seconds of constant 0.6 g, an 8-second period when rotation slowly stopped, and a 6-minute period when aftereffects of rotation could be measured. Cycles were performed every 30 minutes during the initial 3 hours in orbit, and less frequently during the rest of the flight.

The OFO experiment continued until the seventh day in orbit, at which time the onboard battery failed. Recovery of the OFO spacecraft and FOEP hardware were not required.

Results

The experiment was successful. ECG indices showed the flight frogs to be in good health during the entire flight. Vestibular recordings were made as expected. Two equipment malfunctions occurred during the flight: pressure in the canister increased to 11 psi, and the temperature decreased to 55°F for nine hours. However, control experiments performed on the ground showed that these malfunctions had little effect on the outcome of the flight experiment.

Several vestibular response changes were noted during the early period in weightlessness. All of the observed changes reverted to normal during the last 10 to 20 hours of the flight, suggest adaptation.

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The Apollo Program

NASA proposed the Apollo spacecraft for Earth orbital and circumlunar flights in 1960. Capable of accommodating a crew of three, the craft was to be launched by a Saturn 1 type rocket with a thrust of 6,672 kilonewtons. In 1961, President Kennedy announced the goal of landing a man on the moon by the end of the decade. Saturn 5, with a thrust of 33,360 kilonewtons, was developed shortly afterward. By 1962, it was decided that a moon landing could be accomplished by a rendezvous in lunar orbit. A spacecraft (lunar module) would be sent to the lunar surface and returned to a mother ship (command module) orbiting the moon. The first moon landing took place in 1969. Five more lunar landing missions were completed in the Apollo program from 1969 to 1972.

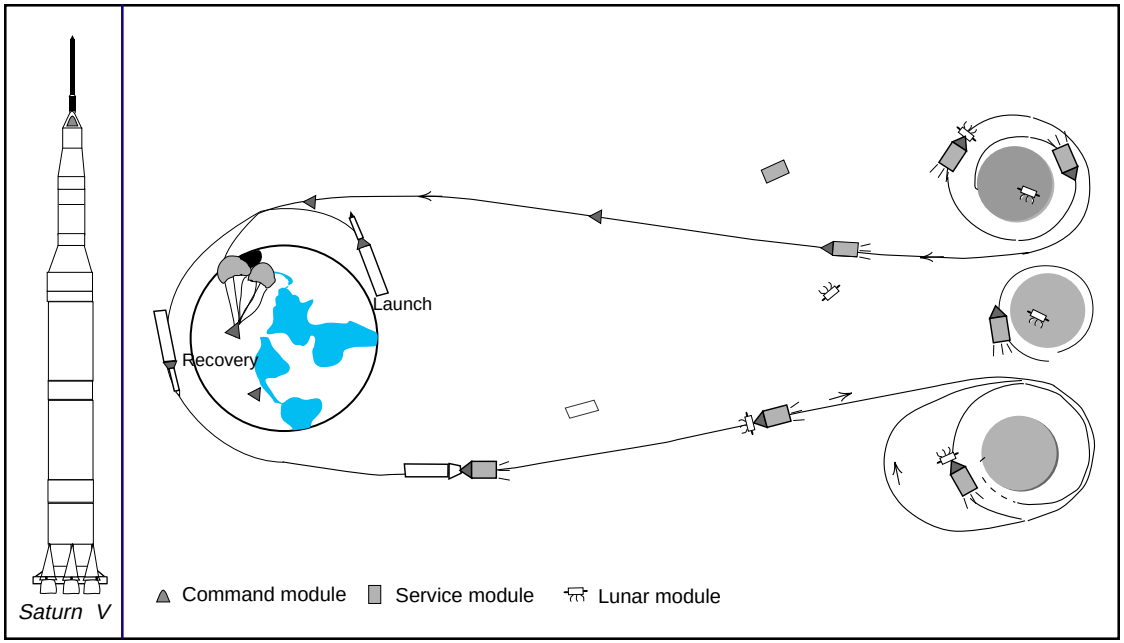

Figure 4-17: Launch and recovery of Apollo 17.

Program Overview

The Mercury capsule had been built for the first U.S. manned space flight program. It could house a single astronaut in orbital flight. A modified Mercury design, with a base diameter of 3.9 meters, was chosen for the Apollo Command Module (Fig. 4-18). It was the control center and the crew habitat, and the module that returned to Earth after mission completion. The Command Module was provided with a radiation shield, and a heat shield to protect it against frictional heat produced when moving through the atmosphere. A Service Module contained most of the mission's consumables. A Lunar Module conveyed astronauts from lunar orbit to the moon's surface. It was designed as a two-stage vehicle because it had to land on and take off from the moon. The descent stage served

as the launch pad for the ascent stage. Since visibility was important, the pilots had to be close to the two rather small triangular windows. There were two hatches. The front hatch was used for access to and from the surface of the moon. The top hatch was used for docking with the Command Module.

A NASA field center was required for the coordinated development of the Apollo program. To satisfy this requirement, the Manned Spacecraft Center (now Johnson Space Center) in Houston, Texas, was established along with a mission control center. This was the site where spacecraft design, testing and checkout, and astronaut crew training could be carried out. Required facilities included a vacuum chamber for testing the spacecraft and crew in a simulated space environment, a centrifuge where the three-man Apollo crew could experience the accelerations of a rocket launch, and other space flight simulators.

Several new technologies, including the rapid development of computer and communication technology, were important in making the Apollo program possible. A worldwide tracking network was necessary to maintain continuous voice contact with the astronauts and telemetry contact with the spacecraft subsystems. During stays on the lunar surface, contact with the astronauts was maintained by means of three antennae spaced equidistantly around the Earth, in Goldstone, California, in Madrid, Spain, and in Canberra, Australia.

Scientific interest in the Apollo program came relatively late, and was generally concentrated in the areas of geology, physics and astronomy; biological research was not a high priority. Only one life

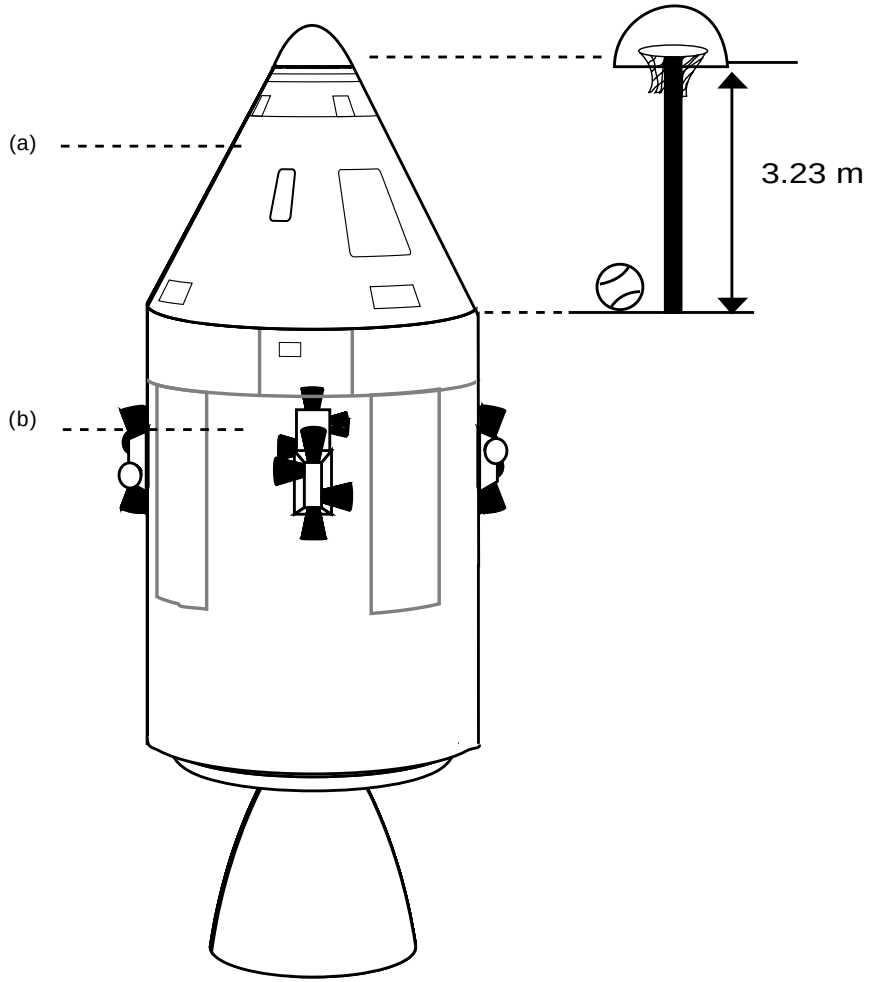

Figure 4-18: The Apollo Command and Service Modules: (a) the Command Module housed the crew and experiment equipment; (b) the Service Module, containing the thrust engine and consumables, was jettisoned before the Command Module re-entered Earth's atmonsphere.

science experiment was conducted by ARC within the Apollo program (the Apollo 17 mission).

Additional Reading

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MISSION PROFILE: APOLLO 17

Mission Duration: 13 days

Date: December 17–30, 1972

Life Sciences Research Objectives

To determine if high-energy cosmic ray particles produce injury to brain, eye, and other tissues

Life Sciences Investigations [pp. 203-208]

Radiation/Environmental Health (A17-1.1, 1.2, 2, 3, 4, 5)

Organisms Studied

Perognathus longimembris (pocket mouse)

Flight Hardware [pp. 462-465]

BIOCORE: Life Support Hardware
BIOCORE: Pocket Mouse Radiation Dosimeters (implanted)

Publications [pp. 404-406]

Apollo 17

The sixth and last of the Apollo series of manned lunar landings was accomplished on the highly successful Apollo 17 mission. Launched on December 17, 1972 from KSC in Florida, it was recovered on December 30, after a total mission duration of almost 13 days.

Scientific objectives of the mission included geological surveying and sampling of lunar materials and surface features, deploying and activating lunar surface experiments, and conducting in-flight experiments and photographic tasks. To achieve these objectives, 12 lunar surface experiments, 5 lunar orbital experiments, photographic and support tasks, and other investigations were carried out.

Seven biomedical experiments were conducted on the Apollo 17 mission. The BIOSTACK experiment (a stack of biological objects and radiation detectors) was designed to study radiation effects on plant and animal systems in a dormant state. An experiment was also conducted to investigate the visual light flash phenomenon in the three-man crew. These two experiments were not conducted under the auspices of ARC, and will not be discussed here. The five remaining experiments performed on the mission related to the Biological Cosmic Radiation Experiment (BIOCORE) package are described below.

Life Sciences Research Objectives

The Van Allen radiation belts are two bands of geomagnetically trapped particles encircling the Earth (Fig. 1-1). Because of their distance from the Earth, exposure to these radiation zones is

currently hazardous to astronauts only on the highest Earth-orbital flights or on flights to the moon. However, since exposure to cosmic particle radiation presents a potential risk to humans as they undertake longer missions farther away from the Earth, the phenomeenon needs to be studied. The BIOCORE package was designed to gain a better understanding of cosmic particle radiation hazards. The objective was to determine if microscopically visible lesions attributable to high-energy (HZE) cosmic ray particle radiation could be found in the tissues of animals flown on the spacecraft.

Life Sciences Payload

Organisms

The pocket mouse (*Perognathus longimembris)* was chosen for the flight experiment for several reasons. This rodent from the arid regions of the southwestern U.S. and northern Mexico does not require drinking water and subsists on seeds and plant material. It is a facultative homeotherm with the ability to drop its metabolic rate dramatically while at rest or in response to environmental stresses such as ambient temperature variations, lack of food, and confinement. Wastes are produced in a concentrated form, and food can be provided freely because the mouse is a natural hoarder. The availability of background information on the animal, and its small size, were also important reasons for its selection.

Five mice were used in the flight study. A control study was conducted on the ground with five other mice. To correlate any observed tissue damage in the heads of the flight mice with the passage of HZE cosmic ray particles, it was necessary to record the trajectories of particles passing through the heads of the mice during flight. For this purpose, plastic dosimeters were implanted beneath the scalps of the mice.

Hardware

Four layers of plastic were sealed together to form the dosimeters. A paralene coating made the units impermeable to the tissue fixatives used after postflight autopsy of the animals. Each dosimeter was mounted on a silicone rubber platform, the underside of which was contoured to the skull. The apparatus covered the entire brain from the olfactory bulbs anteriorly to the cerebellum posteriorly. The assembly was implanted beneath the scalp, where scalp tension fixed its position with respect to the skull. No adverse effects were observed in the mice due to the presence of the subscalp assembly, even after several months of implantation).

Perognathus longimembris, *pocket mouse*

Richard Simmonds

Richard Simmonds is a veterinarian who is internationally recognized as a laboratory animal medicine specialist, and as an advocate for the proper use and care of animals in research. He has a long history of participation in space life sciences projects, including Apollo, Spacelab, and Cosmos. Currently he is Assistant Dean for Research at the University of Nevada in Reno.

Simmonds' first contact with the Apollo Program was in 1970, just after the Apollo 12 mission was completed. At that time, he took part in the Lunar Quarantine Program, which, he says, "reassured the public that the Earth wouldn't be contaminated with moon bugs or organic toxins."

Simmonds played a prominent role in coordinating the BIOCORE on the Apollo 17 mission. BIOCORE was initially proposed for Apollo 16, but problems relating to biocontainment and animal safety made this unfeasible. The version of the experiment flown on Apollo 17 was vastly improved. In Simmonds' view, it received less credit than it deserved. The implanted dosimeters and laser-guided brain coordinate system were very sophisticated. Results were interesting; high-energy particles appeared to have damaged the retinas of the mice. "The evidence was equivocal," says Simmonds, "because you had to believe the predicted trajectory of the particles, and that the lesions seen followed that trajectory." He adds, "We may have euthanized the mice too early. I don't know if there would have been brain lesions too, if we had waited longer." Astronauts have reported seeing light flashes while in space, and it is accepted that these are a result of high-energy particles traversing their heads. It is not known if this phenomenon is related to the lesions seen in the mice on Apollo 17.

Flight and control mice were housed in hermetically sealed cylindrical aluminum canisters. The flight canister remained on the Command Module during the entire mission (Fig. 4-19). In compliance with the constraints imposed by the Apollo spacecraft, the package was a closed, self-sustaining system that required no in-flight handling, data recording, or electrical power. The canister contained seven perforated cylindrical tubes. Six of the tubes were arranged around the inside wall of the canister. The seventh tube was centrally located and contained potassium superoxide granules for converting the carbon dioxide generated by the mice into oxygen. A mouse and its food supply were contained in each of five other tubes. The sixth tube was flown empty because the oxygen generating capability of the environmental control system had been shown to be marginal for six mice. Two maximum-minimum temperature recorders were placed within the canister. A radiation detector external to the package was used to measure the radiation in the vicinity of the canister.

The cylindrical shape and the small bore of the tubes in the canister were designed to minimize tumbling in the microgravity environment, and to enable the mice to move and feed without difficulty. Food consisted of a special seed mixture placed in each tube. No water supply system was required since the mice produce water metabolically from their food.

Operations

The experiment package was flushed with oxygen before launch. The initial supply of oxygen was necessary until the potassium superoxide reaction with carbon dioxide and water vapor was sufficient to generate oxygen at a rate that could satisfy the metabolic requirements of the mice.

The BIOCORE package remained stowed in its designated location throughout the mission. No crew activities were required in relation to the experiment.

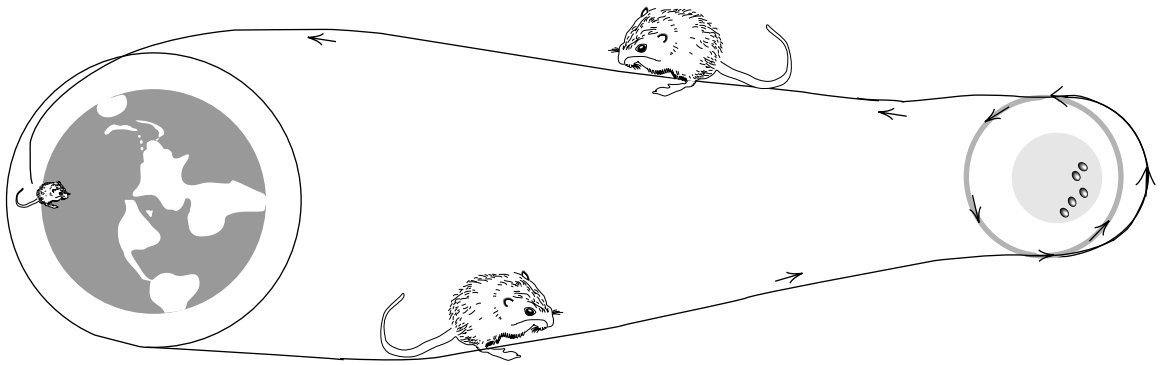

Figure 4-20: Five pocket mice orbited the moon on the Apollo 17 mission.

Results

One mouse was found dead upon recovery of the spacecraft. Of the four that survived the flight, two were quite active. Two were less active, seeming to drag their bodies around as though experiencing a gravitational force greater than 1 g. After euthanasia, autopsies were performed on all of the flight and control mice. The heads of the mice were then fixed and radiation damage assessed.

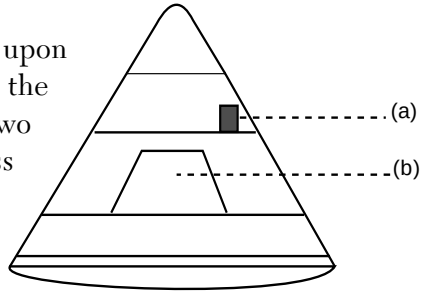

Fig. 4-19: Location of the mouse canister on the Apollo spacecraft: (a) mouse canister; and (b) crew hatch.

The general condition of the flight animals appeared to be related to the level of hemorrhagic materials in the middle ear cavities. Massive hemorrhage was found in the animal that was dead at recovery. No hemorrhage was seen in the animal that was in the best condition after the flight. Ground control animals also showed similar hemorrhaging. Similar effects had been noticed during preflight tests, and were probably due to pressure excursions in the potassium superoxide canisters.

Lesions in the scalps of the flight mice provided only circumstantial evidence of vulnerability to radiation from cosmic ray particles. Other effects were noted in the olfactory epithelium and in the middle ear cavities, but their causes were unknown.

Although no brain lesions were observed, this does not negate the possibility that HZE cosmic ray particles are injurious to brain tissue. Spacecraft shielding may have been so effective that high energy cosmic ray particles did not reach the mice. Less shielded exposures to cosmic ray particles would be needed to prove the presence or absence of effects on brain and other tissues. The tissue fixative used was later found to be less than optimal; this may also be a reason for the lack of demonstrable brain lesions.

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Skylab Program

The first serious attempt at formulating a concept for a space station was put forward by Hermann Oberth in 1923. The scientific community gradually became interested in such a station, realizing that it would enable them to study the physical and psychological effects of space flight on man. NASA began considering plans for a manned space station in the 1950s, but the Skylab Program only came into being in the mid-1960s. In the early days, it was called the Apollo Applications Program. Costs were to be kept to a minimum by reusing existing Apollo hardware to build and operate the space station.

The Skylab space station was launched on May 14, 1973 on the unmanned Skylab 1 mission. About one minute after launch, some serious technical problems arose. Aerodynamic stress tore loose the thin aluminum structure that acted as the station's meteorite shield and sunshade, together with one of the two electricity-producing solar arrays. The other solar array failed to deploy properly as a result. Absence of a sunshade meant that temperatures were high inside the space station, and there were concerns that toxic materials would be released, and that food and film onboard would be spoiled. On May 25, 1973, a three-man crew was launched on the Skylab 2 mission to attempt to repair the damage to the station. The crew put up a parasol-like structure to replace the lost sunshade. The temperature inside the station then dropped enough for the crew to enter. The one remaining solar array was eventually made operational, making electricity available.

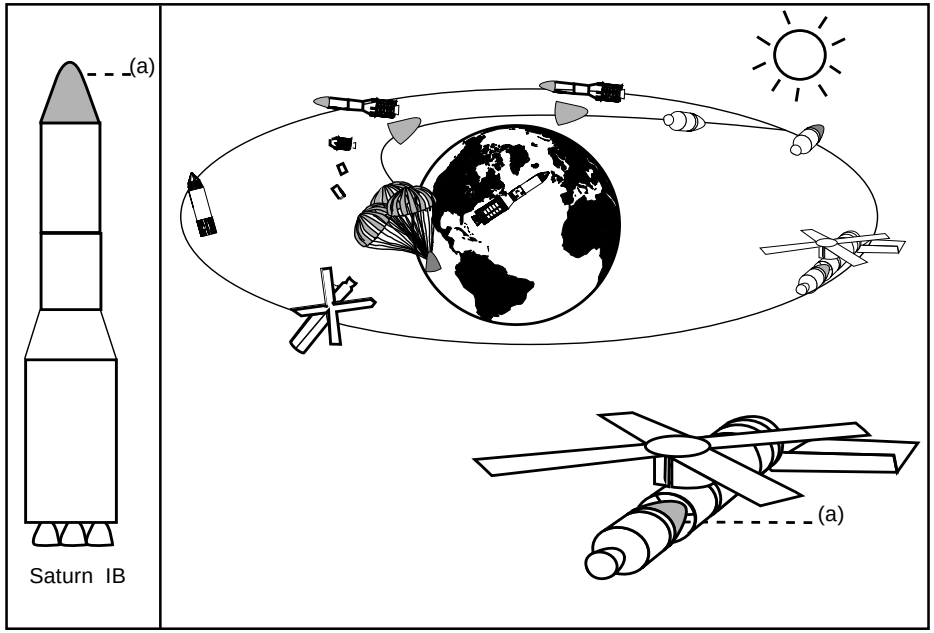

Figure 4-21: Launch and recovery of the Skylab crew module; (a) Crew module.

The Skylab Program demonstrated several important points about space flight. First, it showed that man could live and operate effectively in space for long periods of time. The near-disaster that occurred soon after the Skylab 1 launch was evidence that repairing equipment in space was feasible. The program also indicated that free-flying unmanned laboratories were needed for conducting experiments which required an environment that was undisturbed by astronaut and maneuvering activities. NASA's in-

terest in having unmanned platforms on the International Space Station stem directly from the Skylab experience.

The Skylab Space Station

The Skylab space station was really a modified S-IVB stage of a Saturn V moon rocket, whose hydrogen tank had been converted into accommodations for a three-man crew. Weighing about 100 tons, Skylab had a habitable volume of approximately 283 m^3. Its two stories were separated by a metal grid floor into which the astronauts' cleated shoes could be locked for stability. The upper floor had storage lockers and a large area for conducting experiments. The lower floor was the living quarters; it had three bedrooms, a dining table, a work area, a shower, and a bathroom. Food, water, and clothing for the nine astronauts who were to eventually occupy the space station were stored in lockers. The air supply was an oxygen-nitrogen mixture at a pressure of 5 psi. The temperature of the interior was designed to be maintained at about 70°F.

The solar arrays on the station could each provide about 10,500 watts of power at 55°C, while the station was in the sunlit portion of its orbit. Some of this power was stored in batteries for use when the station was shielded from the sun by the Earth's shadow.

The Skylab was put into orbit by the giant Saturn V launcher. Modified Apollo command and service modules launched by smaller Saturn IB rockets ferried crew members to and from the space station. A docking adaptor on the Skylab allowed the Apollo spacecraft to dock with the station and transfer its cargo of crew members.

The Skylab 2 mission lasted for 28 days. The next two missions, Skylab 3 and Skylab 4 lasted 59 and 84 days, respectively. All three manned Skylab missions occurred within a period of nine months. The space station was deactivated between missions. The Skylab remained in orbit for more than five years after the last crew left the station. The plan had been to use a Space Shuttle mission to attach a rocket stage to the Skylab for boosting it to a safe altitude. However, the Shuttle was still in development, and it became evident that this solution would not be feasible. In early 1979, the Skylab was reactivated and adjustments were made to minimize atmospheric drag and control its altitude. Some parts of the station, such as the heavy lead film vaults were not expected to burn up during re-entry. To avoid risks to highly populated areas, flight controllers steered the station towards the Indian Ocean. It finally crashed to Earth in Western Australia on July 11, 1979.

A large number of life sciences experiments were conducted on the three manned Skylab missions. Two of these were developed by ARC. Both were flown on the Skylab 3 mission.

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MISSION PROFILE: Skylab 3

Mission Duration: 59 days

Date: July 28–September 25, 1973

Life Sciences Research Objectives

To study circadian periodicities during space flight

Life Sciences Investigations [pp.212-213]

Regulatory Physiology (CPE-1, 2)

Organisms Studied

Perognathus longimembris (pocket mouse)
Drosophila melanogaster (fruit fly) pupae

Flight Hardware [pp.478-481]

Circadian Periodicity Experiment Package
Pocket Mouse Housing Unit
Vinegar Gnat Enclosures
Circadian Data System

Publications [p. 407]

Skylab 3

The Skylab 3 mission began on July 28, 1973 when a three-man crew arrived at the Skylab station in a modified Apollo spacecraft. During their 59-day stay onboard the space station, the crew members conducted several experiments, including two life sciences investigations developed by ARC.

Life Sciences Objectives

The objective of the first experiment was to study the stability of the circadian rhythm of a mammalian system during space flight. The other experiment was designed to study the phenomenon of temperature compensation in an insect's circadian rhythm. Because the objectives of the two experiments were similar, they were packaged together as an integrated unit, which remained attached to Skylab for the duration of the mission. The unit was installed in the Apollo command service module.

Life Sciences Payload

Organisms

The first experiment used the pocket mouse *(Perognathus longimembris)* as the experiment subject. This species was chosen for study for several reasons. First, it is easy to maintain in caged conditions. Since it is a natural hoarder, food can be provided freely. It produces water metabolically from its food, and so does not require a supply of drinking water. As a result, feces are produced in small, concentrated amounts. Second, it is well suited

for studies of circadian periodicities because it shows remarkable precision in the timing of daily periods of lowered body temperature, or torpor. Third, its small size allows a larger number of subjects to be used in the experiment. Six mice were used in the flight experiment. All were implanted with biotelemeters for monitoring body temperature and activity.

The other experiment used 180 pupae of fruit fly *(Drosophila melanogaster)*. They were divided into four groups. Flashes of light were to be delivered to the pupae to stimulate emergence of adult flies at different times during the flight. The objective was to determine whether the daily rhythm was disturbed in microgravity.

Hardware

Pocket mice were kept in individual circular cages that were placed in a common enclosure. Each cage was lined with porous polyethylene and contained 50 grams of dried seeds. A small fiberglass tube at the center of each cage contained the receiving antennas for the implanted biotelemetry unit. A thermistor monitored the ambient temperature in each cage. An environmental control system maintained cage air pressure at about 700 mm of mercury and the relative humidity at about 20 percent.

The data system consisted of a data processor, memory, and power supply. It collected data on biological, environmental, and engineering parameters for both experiments. One accumulated activity count and one body temperature reading was recorded every 10 minutes from each pocket mouse for the duration of the experiment. Ambient temperature recordings were made every 10 minutes. Engineering parameters were recorded every 40 minutes.

Fruit flies were housed in four sealed enclosures. Each enclosure contained a pupa plate that could be warmed to induce hatching, a temperature control system, a programmable stimulus lamp, and a photodetector for counting hatchings. A relative humidity of about 62 percent was maintained at the surface of the pupa plates. The data system was designed to collect data on lamp status, population count and temperature of the housing enclosure and pupa plates.

Operations

Collection of preflight baseline data from the flight and control mice began about 40 days before the mission. The flight mice were placed in flight hardware in dark conditions six days before launch. The hardware was loaded into the command service module two days later.

The mouse holding unit operated perfectly for the first 30 hours after launch. The fruit fly experiment was initiated, temperatures in the pupa plates were raised to 20°C, and the stimulus lights came on at the appointed time. Unfortunately, about 30 hours after launch a power failure occurred and resulted in the loss of both experiments. The ground controls were operated for about a month after the loss of the flight experiment. The control data was expected to be useful in the event that the function of the

flight hardware could be restored, or, in the case that the flight experiment was re-flown, on a later mission.

The data from the flight mice and the ground control data obtained during the 30 hours prior to the hardware malfunction were analyzed.

Results

Mice

The investigators concluded that meaningful results could have been obtained if the animal holding unit had continued to function because the telemeters were able to provide reliable data.

Fruit flies

No useful scientific data were obtained because of the power failure.

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The Space Transportation System

After the Skylab missions were terminated, the U.S. space program became centered on establishing a permanently manned orbiting space station. A reusable launch vehicle was to be used to ferry crew and equipment between Earth and the station. Because of the cost involved in building a space station, the project's aims were modified in time, and the Space Transportation System (STS) program came into being.

Program Overview

The STS is a launch system that can be used to place a variety of payloads into low earth orbit. When it was conceived in 1969, it was intended to be fully recoverable. Because of the high development cost, the concept was abandoned in favor of the present system. In the current scheme, the orbiting spacecraft is attached at launch to two solid fuel rocket boosters and an external liquid fuel tank. Shortly after launch the solid fuel rocket boosters detach from the orbiter and parachute to the sea. The empty casings are recovered and later reused. The external liquid fuel tank is also jettisoned after launch, and burns up during re-entry. Despite the compromise, the STS provides a unique service as a reliable, reusable heavy-lift booster, capable of carrying a payload of almost 23 metric tons into orbit.

The main component of the STS is the Space Shuttle. Other components include the Spacelab and various accessories that are used during flight, as well as ground facilities where the Shuttle is assembled, launched, and recovered.

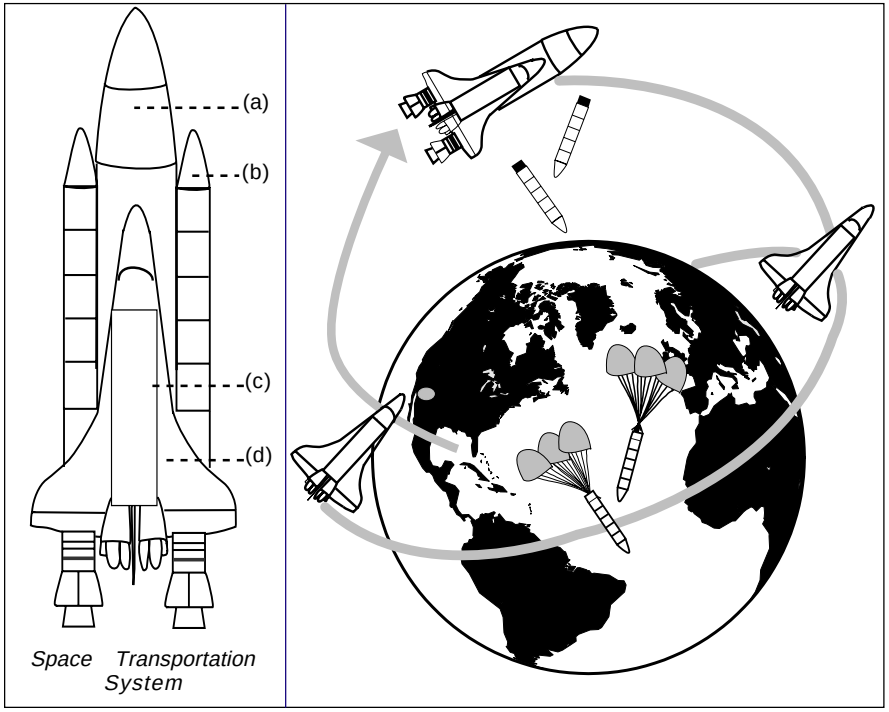

Figure 4-22: STS launch and recovery: (a) External tank; (b) solid rocket booster; (c) payload bay; and (d) orbiter.

The Space Shuttle

The Space Shuttle is made up of three major parts: a reusable orbiter, a pair of solid-propellant boosters, and a liquid propellant tank. The orbiter, appropriately, is the portion of the Shuttle that travels in Earth orbit. However, the distinction between the Shuttle

1982	1983	1984	1985	1986	1987	1988	1989	1990
STS-3	STS-8	STS-10	STS-51B				STS-29	STS-32
Mung Bean Seedlings	*Rats*	*Rats*	*Rats*				*Rats*	*Fungus*
Oat Seedlings			*Squirrel Monkeys*				STS-34	STS-41
Pine Seedlings			STS-51F				*Corn Seedlings*	*Rats*
			Mung Bean Seedlings					
			Oat Seedlings					
			Pine Seedlings					

Table 4-3: Organisms studied on ARC Space Shuttle missions.

and the orbiter is not always made clear, and the two terms are often used interchangeably. The four orbiters currently in operation are Atlantis, Columbia, Discovery, and Endeavor, and are named after pioneer sailing ships. Each orbiter was engineered to be capable of completing more than 100 missions, each lasting about 10 days. Columbia is being modified into an Extended Duration Orbiter which will be able to accommodate missions of up to 16 days. Endeavor, the newest of the orbiters, replaces the orbiter Challenger, which was lost in a tragic explosion in 1986.

The Space Shuttle is designed to carry out three main tasks. First, it functions as an orbiting space laboratory. The Spacelab, described below, complements and extends this capability. Second, it can be used to carry commercial and government-sponsored payloads that can be placed into a low Earth orbit or a transfer orbit as satellites. Third, it provides maintenance service in repairing and resupplying satellites and returning them to Earth.

The payload for a particular Shuttle mission consists of items destined for similar orbits, and is subject to the availability of space, weight, and other factors, such as power. Payloads frequently include experiment packages for conducting life sciences research in microgravity. Such research is constrained by the necessary emphasis on crew safety. The need for rigorous ground testing and safety verification has associated costs and lengthy flight preparation periods. However, the research opportunities presented by Shuttle missions dwarf these disadvantages. The value of conducting research on the Shuttle lies mainly in the fact that it is a manned vehicle. Crew members can carry out manual procedures in orbit, make real-time decisions and intuitive judgments, and gather data that often cannot be easily obtained on unmanned biosatellite missions.

Experiments can be accommodated in either the middeck or the payload bay (Fig. 4-23). The middeck is located below the flight deck of the orbiter, adjacent to the payload bay. Forty-two modular lockers are situated in this area, primarily for storage of crew food, clothing, and payload support equipment. Unused space within the lockers can be appropriated for small, low-power experiments that can be simply operated or observed by the crew. The experiment packages are required to be self-sufficient in terms of data acquisition and instrumentation capabilities. There are several advantages to conducting experiments on the middeck, despite the limited resources available. These experiment packages require less time

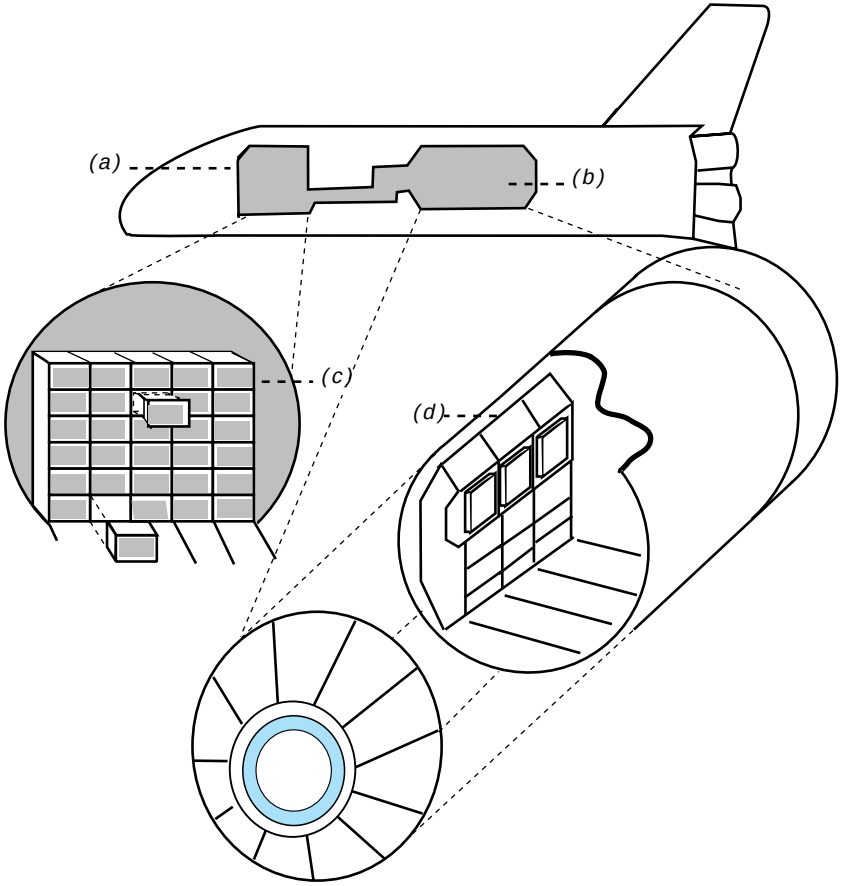

Figure 4-23: Life sciences experiment sites on the STS: (a) middeck; (b) lockers where experiments are stored in middeck; (c) Spacelab; and (d) racks for experiments in Spacelab.

and cost for development than experiments on Spacelab, and consequently can be flown more frequently. Crew operations are feasible as in the Spacelab. Since the complex loading and retrieval procedures used for Spacelab experiments are not required here, experiment packages can be loaded shortly before launch, and recovered soon after landing. Several units of hardware, including an advanced animal habitat, a refrigerator/ incubator module, and a space acceleration measurement system are expected to be flown on the middeck in future flights.

Small economical payloads can be carried in the orbiter's cargo bay to maximize the use of space. A small payload known as the Hitchhiker is sometimes included in the cargo bay. Equipment included in a Hitchhiker should require only modest resource and space allocations and should not need special positioning or access to orbiter computers. Simple, self-contained experiments can also be held in the payload bay in Get Away Special carriers. All electrical power, heating, cooling, and data acquisition systems for these investigations must be provided by the experimenters.

Experiments on the Shuttle can be controlled through the orbiter, the Spacelab, or the ground. The orbiter communication system accomplishes information transfer to the ground during flight via the Spaceflight Tracking and Data Network, or via the Tracking and Data Relay Satellite System. Onboard control of data and subsystems is achieved by means of a data management subsystem, which is capable of recording data or transmitting it directly to the ground (Fig. 4-24). Computer terminals and about 750 watts of power are available in the aft flight deck of the orbiter. The

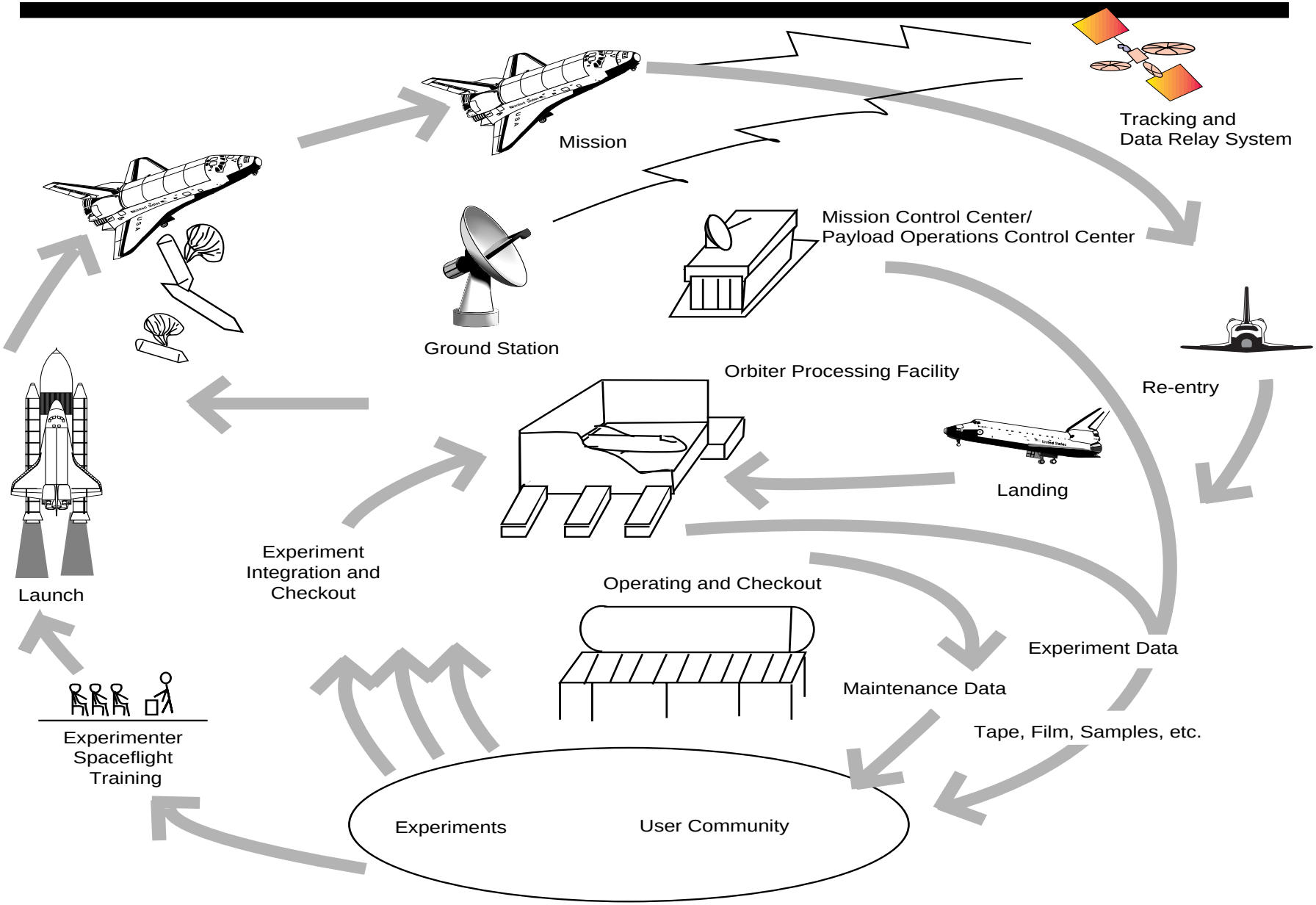

Figure 4-24: Experiment equipment on the Spacelab is controlled by a data danagement subsystem. Data is transmitted to the ground via the Tracking and Data Relay Satellite System.

crew maintains voice contact with scientists and mission personnel on the ground via an intercom system. A closed circuit television system is also available.

Through December 1990, nine Shuttle missions have flown life sciences experiments sponsored by ARC. Only one of the nine missions, STS-51B in 1985, used the Spacelab facility for life sciences experiments. The other eight missions carried middeck payloads: STS-3 in 1982; STS-8 in 1983; STS-10 in 1984; STS-51F in 1985; STS-29, STS-34, and STS-41 in 1989; and STS-32 in 1990. The payloads on STS-8, STS-10, and STS-29 were a part of the Shuttle Student Involvement Project.

Spacelab

Spacelab, as its name implies, is a reusable space-based laboratory. It is designed to be taken to orbit and returned to Earth in the large cargo bay of the orbiter. Besides simply increasing the habitable volume of the orbiter, it provides astronauts with the myriad research tools commonly found in a standard ground laboratory. A modular construction permits it to be modified to optimally accommodate different experiments on separate missions. Three basic configurations are offered by the Shuttle/Spacelab design: module only, module and pallets, or pallets only. Each pallet or equipment platform has electrical power, data lines and cooling capability. When a Spacelab module is not flown in the pallets only mode, computers and data handling equipment are housed in an "igloo," a cylinder mounted on the first pallet which provides a pressurized and thermally controlled environment for the equipment.

Either a long or a short module may be used on a particular mission, together with one or more pallets. A long module measures 7 meters in length, and a short module 4.3 meters in length. The modules are pressurized to 1 atm so that the crew can work within in an environment similar to that of Earth. Experiments are housed in racks within the laboratory module, and are supplied with electrical power, thermal control, and data lines. Each rack can hold 290 kg of equipment. Large hardware items that do not fit in a rack are installed in the center aisle of the Spacelab. A laboratory work bench is also provided. The crew can control or monitor the equipment and the subsystems of the Spacelab via a computer keyboard and a visual display system.

At this time, Spacelab has three primary functions. It serves as a research laboratory, an observation platform, and as a development testing ground for future space ventures. In the future, it may also act as a limited production facility in space.

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MISSION PROFILE: STS-3/ OSS-1

Mission Duration: 8 days

Date: March 22–30, 1982

Life Sciences Research Objectives

To study the influence of microgravity on lignification in plant seedlings

Life Sciences Investigations [pp. 217–219]

Plant Biology (OSS-1 1.1, 1.2, 1.3)

Organisms Studied

Pinus elliotti (pine) seedlings
Avena sativa (oat) seedlings
Vigna radiata (mung bean) seedlings

Flight Hardware [pp. 506-507]

Plant Growth Unit (PGU)

Publications [pp. 407-408]

STS-3/Office of Space Sciences (OSS-1)

The third Space Shuttle mission, STS-3, was launched on March 22, 1982 and completed on March 30, 1982. On this eight-day flight, the Space Shuttle Columbia carried two crew members and a payload designated OSS-1.

The STS-3 mission was the third in a series of four Shuttle missions that constituted the Orbital Flight Test program. The NASA Office of Space Science, now known as the Office of Space Science and Applications, developed the OSS-1 payload. The primary objective of the Orbital Flight Test program was to assess the performance of the orbiter and its flight systems. Because of this, the objectives of the experiments in the OSS-1 payload were secondary to, and constrained by, the flight test operations.

Nine experiments were included in the payload. Besides observations of the orbiter's environment, studies were conducted in space life sciences, astronomy, and space plasma physics. Specific objectives of the OSS-1 payload were to observe aspects of the orbiter's environment with relevance to plasma physics and astronomical payloads; to conduct scientific observations that demonstrate the Space Shuttle's research capabilities; and to evaluate technology that may be applied to future experiments in space.

The experiments selected used many of the unique capabilities of the Shuttle, such as the ability to carry large instruments into orbit, to operate them in space under crew supervision, and to return them to Earth. In many respects, OSS-1 was instrumental in

preparing the way for more sophisticated payloads on later Shuttle missions.

The life sciences experiment was carried on the Shuttle middeck. All other experiments were mounted on a Spacelab pallet in the orbiter's cargo bay.

Life Sciences Research Objectives

The OSS-1 plant growth experiment was designed to determine if lignification is a response to gravitational forces, or a genetically determined process with little environmental influence. Lignin is a structural polymer that enables plants to maintain a vertical stature despite the pull of gravity. Although lignin is necessary for plant growth in Earth gravity, it consumes a significant amount of a plant's metabolic output, and has no food value. Specific objectives of the experiment were: to test the function of the Plant Growth Unit (PGU) in supporting plant growth in space; to determine the effect of microgravity on lignin synthesis; and to observe the overall development of young seedlings exposed to the conditions of space flight.

Life Sciences Payload

Organisms

Plants used in the experiment were mung bean (*Vigna radiata*), oat (*Avena sativa*), and pine (*Pinus elliotti*) seedlings. A gymnosperm (pine) was used as the principal plant species because of its capacity to synthesize large amounts of lignin; all gymnosperms are believed to be affected by gravity. Young seedlings were used because of space limitations and the relatively short flight duration. These seedlings were germinated a few days before flight, so that significant growth could occur during flight. Mung bean and oat seedlings were selected as representatives of dicotyledons and monocotyledons respectively, and were germinated only hours before launch. Sixteen seedlings of each species were flown, in six plant growth chambers.

Hardware

Since this was one of the first Shuttle experiments to use plants as experimental subjects, a PGU was built to be used on this and subsequent missions. The unit was designed to replace a locker on the forward bulkhead of the orbiter middeck. It consisted of various support components and a cavity for containing plant growth chambers. The PGU was equipped with three plant growth lamps and a timer for day/night cycling. Temperature sensors, electronically controlled fans, heater strips for temperature modification, a data acquisition system, and internal batteries were also included in the unit. Plants were grown in six individual plant growth chambers that fit into the PGU cavity (Fig. 4-25). Each chamber had a volume of about two liters. The chamber base was fitted with a temperature probe and two gas sampling ports. Seeds were planted in a "sandwich" support medium contained in the base of the chamber.

Operations

Preflight activities commenced about two weeks before launch, when pine seeds were planted daily to ensure the availability of enough seedlings. After seeds were sown in the plant growth chambers, the chambers were sealed and purged with compressed

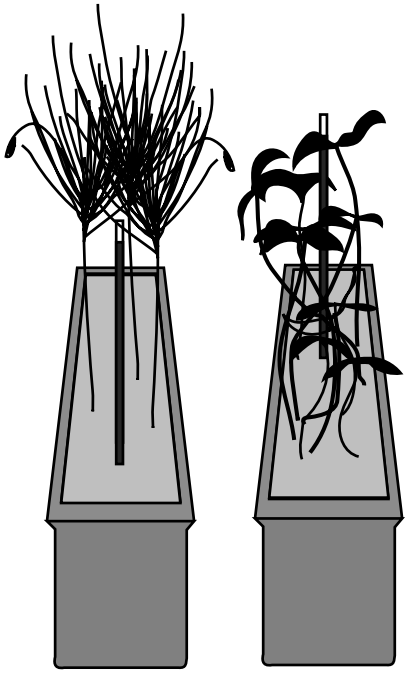

Figure 4-25: Two plant growth chambers inside the PGU.

air of a defined composition. The chambers were loaded into the flight and backup PGUs. The backup unit was maintained in a ground facility as a 1 g control, and the flight unit was installed in the orbiter. The PGU design allowed the seedlings to be oriented normally with respect to gravity while the orbiter was on the launch pad.

Because the PGU was a self-sufficient system, it required little attention during flight. The crew transmitted temperature readings of the growth chambers to the ground several times daily, so that these values could be compared to the temperatures of the control experiment.

The Shuttle landing was delayed by one day because of high winds at the White Sands landing site in New Mexico. The experiment teams saw the delay as an opportunity to perform additional science. Unfortunately, science data could not be gathered during the extra day because of the need to conserve the orbiter's energy resources.

Touchdown finally occurred at White Sands after a 194-hour mission. A temporary laboratory had been assembled in a motor home near the landing site. Once the PGU was recovered, gas sampling and analysis, visual observations, and photography were performed. Further analyses were conducted in the investigator's laboratory.

Results

The PGU functioned well in the space environment, and was shown to be suitable for use on the upcoming STS-51F mission. Several observations and measurements showed an apparent effect of microgravity on plant growth and development. Plants grew toward the light source as anticipated. Unexpectedly, however, the roots of the plants also grew upward or towards the light source. Positive indications that lignin synthesis is affected by microgravity were examined further on the STS-51F mission.

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MISSION PROFILE: STS-51B/Spacelab 3

Mission Duration: 7 days

Date: April 28–May 5, 1985

Life Sciences Research Objectives

Evaluate operations and procedures for in-flight care of animals
Assess in-flight biocompatibility between animals and RAHF
Study physiological, morphological and behavioral changes in animals

Life Sciences Investigations [pp. 220-249]

Animal Maintenance (SL3-1.1,1.2)
Cardiovascular/Cardiopulmonary (SL3-2, 3)
Immunology/Microbiology (SL3-4)
Musculoskeletal (SL3-5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16)
Neuroscience (SL3-17, 18, 19)
Regulatory Physiology (SL3-20, 21, 22, 23, 24, 25, 26, 27,28, 29)

Organisms Studied

Saimiri sciureus (squirrel monkey)
Rattus norvegicus (rat)

Flight Hardware [pp. 540-549, 488-489, 466-467]

Research Animal Holding Facility
RAHF Rodent and Primate Cage Modules
Dynamic Environment Measuring System (DEMS)
Biotelemetry System (BTS)

Publications [pp. 409-419]

STS-51B/Spacelab 3

The STS-51B mission was launched onboard the Space Shuttle Challenger on April 28, 1985 and recovered on May 5, 1985. The mission was also called Spacelab 3 (SL-3), because it was the third Shuttle mission scheduled to use the Spacelab.

Although the primary objective of the STS-51B mission was to conduct materials science experiments in a stable low-gravity environment, important research was conducted in life sciences, fluid mechanics, atmospheric science, and astronomy. Scientists from the U.S., France, and India carried out a total of 15 investigations in these disciplines. The Shuttle carried a crew of seven, including two payload specialists and three mission specialists.

Several life sciences investigations using nonhuman subjects were conducted on the mission. This research was particularly significant because it involved the introduction and flight verification of the Research Animal Holding Facility (RAHF). The RAHF is a self-contained system that houses and provides life support for animals in space. Two RAHFs were flown on the mission, one contained 24 rats and the other contained 2 squirrel monkeys.

Life Sciences Research Objectives

The primary life sciences research objective of the mission was to evaluate the RAHF's capability to maintain animals in an environment comparable to a ground-based vivarium. This is vital to experiments conducted in space because uncompromised data on the physiological and behavioral effects of microgravity can only be

obtained from healthy animals. In addition to fulfilling this objective, the mission provided valuable baseline data on various physiological parameters. The mission was also able to address the issue of possible risks to the crew's health and comfort. This was of some concern because for the first time, crew members and animals were confined together within the enclosed environment of the Spacelab.

Specifically, the research objectives for the SL-3 mission were to: evaluate operations and procedures for in flight animal care; assess in-flight biocompatibility between the animals and the RAHF; gain mission operational experience; study the physiological, morphological and behavioral changes that occur in animals as a result of being contained in the RAHFs during space flight; and verify the principal hardware elements to be flown on later missions.

Life Sciences Payload

Organisms

Two adult male squirrel monkeys (*Saimiri sciureus*) were flown unrestrained in individual cages in the primate RAHF. The objective in flying these animals was to observe gross physiological and behavioral changes in response to space flight, and to evaluate the adequacy of the RAHF to house and support them in space.

Both monkeys were free of various specified pathogens. Only six months prior to flight, it was decided that the monkeys should also be free of antibodies to the *Herpes saimiri* virus, because of crew safety considerations. Although the *Herpes saimiri* virus is not known to cause disease in either squirrel monkeys or humans that carry it, problems have been documented in other species. A worldwide search was initiated to find *Herpes saimiri*-free animals. Five were eventually located, but time limitations permitted only two of them to be trained for flight. Instruments were not implanted in the monkeys because of time constraints.

The rodent RAHF contained 24 individually housed male albino rats (*Rattus norvegicus*) that were certified free of several specific pathogens. Half of the rats were rapidly growing juveniles, weighing approximately 200 grams at flight. The remainder were mature 12-week old rats, weighing approximately 400 grams at flight. All rats were flown unrestrained. Before the flight, four of the rats were surgically implanted with biotelemetry transmitters.

Hardware

Each primate cage contained a removable solid window through which crew members could view the animal (Fig. 4-26). A perforated window beneath this allowed limited access to the animal. A temporary restraint system could be activated to restrain the animal in flight in the event of an emergency. Airflow directed urine and feces to absorbent, removable trays beneath the grid floor of the cage. Two infrared light sources and two activity sensors located at opposite sides of the cage were used to monitor animal

Rattus norvegicus, *rat*

William Berry

William Berry was the Chief of the Life Sciences Flight Projects Office at ARC during the Spacelab 3 era. A mechanical engineer by training, he has been involved in several ARC projects, including wind tunnel development, Biosatellite III, the Biomedical Experiments Scientific Satellite, Pioneer Venus, and Viking Biology Instrumentation. He is currently serving as Acting Director for Space Research at ARC.

Berry described the way the RAHF came to be flown on the Spacelab 3 mission. "It was really fortuitous. The Vestibular Research Facility had originally been scheduled to fly on the mission. When it became obvious that this facility was not going to be developed in time, the idea of verifying the RAHF concept came up. The science was later piggybacked on the engineering verification of the RAHF."

Spacelab 3 was the first mission to fly humans in close proximity with animals. "There was a lot of opposition to the idea from the astronauts," says Berry. There was concern that the crew might be contaminated by the animals because of the enclosed environment of the Spacelab. During the flight, a leak in the RAHF allowed some particulates to escape the animal cages. "When this became public knowledge, the popular press had a field day. But in reality, there was never any danger of contaminating the crew with pathogens from the animals."

The purpose of flying the RAHF was to enable the crew to handle the animals. "Because of this, we focused on flying 'clean' specimens, rather than on building a system that totally isolated the crew from the animals," Berry explains. Considerable effort was spent to find monkeys that were not carrying the *Herpes saimiri* virus.

At first, there was some concern that animal rights activists would react strongly to the idea of having animal subjects aboard the Spacelab. "This turned out to be a nonissue," Berry says. A member of the Humane Society was invited to KSC to observe the preflight operations. "There was no problem once it became evident that the flight monkeys were not going to come to any harm. Of course, we made it clear that the flight rats were going to be euthanized after the mission. But this was only being done because we needed to understand the effects of microgravity on body tissue."

Berry realized the value of the Spacelab 3 mission. "It allowed us to solve a number of problems that later benefited the Spacelab Life Sciences-1 mission. One problem was getting unanimous agreement on the definition of a specific pathogen free animal. Finding a means of moving the animals onto the Spacelab was another hurdle that was successfully overcome. But as far I was concerned, the most important success criterion for the mission was bringing the animals back alive. This really was one of our main goals, whether stated explicitly or not."

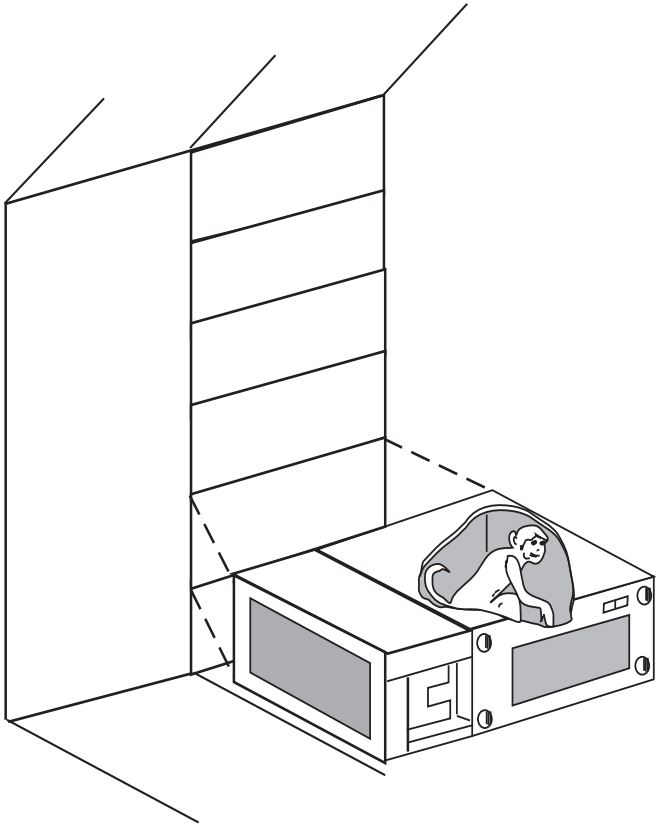

Figure 4-26: Primate cage in the RAHF.

movement. Periodic video recordings were made of the monkeys to evaluate their response to space flight.

Rodent cages were similar in design to the primate cages (Fig. 4-27). Two rats were housed in each cage, separated by a partition. A camera mirror system was installed to record the movements and behavior of four of the rats during launch and re-entry.

The RAHFs were designed to provide life support in a manner comparable to vivarium housing on the ground. Besides providing access to food and water and effective waste removal, the facility also permitted environmental factors such as lighting, temperature, and humidity to be maintained within a specified range. An environment control system circulated conditioned air through the cages to control temperature and humidity, and facilitated air exchange with the Spacelab.

Food and water consumption were monitored as an indicator of animal well-being and a measure of the normalcy of circadian periodicity. Water consumption was measured electronically when the Lixit reservoirs in the cages refilled after being emptied by the animals. Animals could manipulate a tap switch to activate feeders filled with banana pellets. A pellet counter monitored food consumption. Rodent food was presented in the form of a bar. The food bar advanced as the rodents gnawed on its end, and consumption was monitored by an event counter which sensed the forward movement of the bar.

The crew evaluated general animal well-being through the viewing windows on the cages, and by monitoring food and water intake using the Spacelab computer. An onboard control panel could alert crew members to hardware malfunctions such as water leaks.

An automated biotelemetry system (BTS) was used to monitor animal body temperature, heart rate, and electrocardiograms. The BTS consisted of a surgically implanted transmitter, an antenna on each RAHF cage, a receiver, and electronic interfaces with a dedicated computer. The output from the implanted sensors first went to an onboard computer, which reformatted the data and then transmitted it to the ground.

There were four monkey cages in the primate RAHF equipped with BTS capability. However, physiological data was not obtained from the two flight monkeys because neither was outfitted with sensors. Physiological data was obtained from the four rats implanted with biotelemetry transmitters.

Another measurement system, the dynamic environment measurement system (DEMS), recorded noise, vibration, and acceleration levels in the immediate vicinity of the RAHF during launch and re-entry. This data was expected to be important for designing future experiments and for interpreting results of studies affected by the environment outside the RAHF.

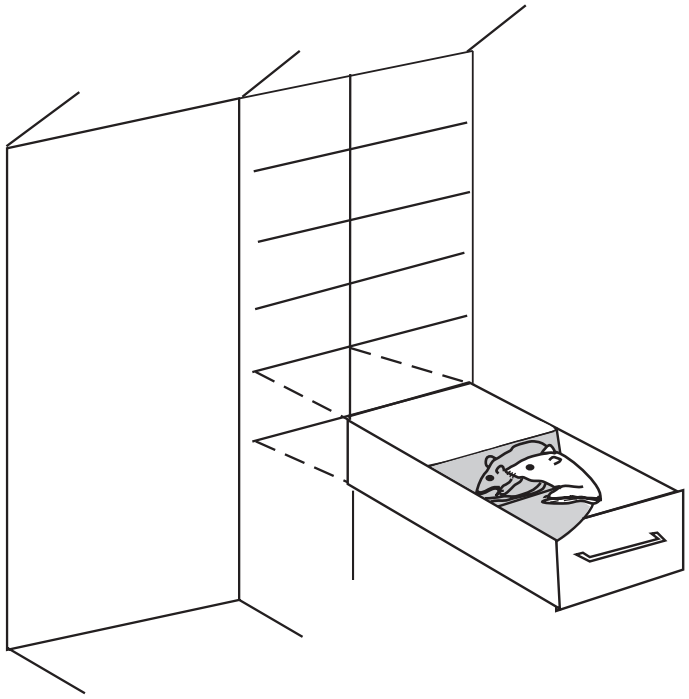

Figure 4-27: Rodent cage in the RAHF.

Operations

The execution of the mission involved simultaneous activities at three NASA centers: Hangar L at KSC in Florida, ARC in California, and the Payload Operations Control Center at JSC in Texas. Although the mission was successful, several obstacles had to be overcome at various stages during mission development and the in-flight period.

Design, testing, and successful hardware integration required a major cooperative effort between the various NASA centers involved in the mission. The RAHF was originally designed as an animal transporter to be launched in the middeck of the Shuttle. It was to be installed in the Spacelab after launch. This concept was abandoned because it was difficult to move the bulky transporter down the tunnel connecting the middeck and Spacelab. The idea of mounting the transporter in the Spacelab aisle in order to maintain the vertical orientation of the animal cages at landing also turned out to be impracticable. The final design involved installing individual cages in the RAHF while the Shuttle was in its vertical position on the launch pad. This meant that the animals would be resting on the cage side at landing.

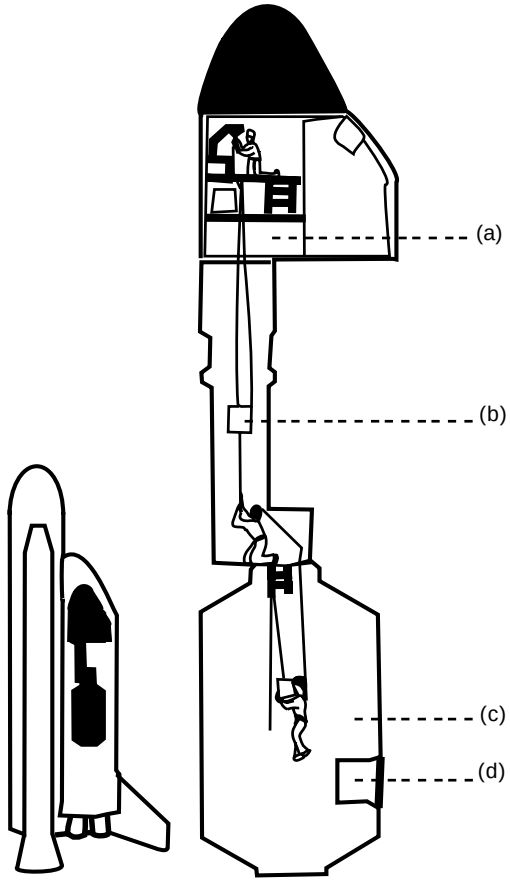

Figure 4-28: The MVAK allows biological materials to be loaded into the Spacelab late in the STS launch sequence, after the spacecraft has been assembled and placed in vertical position: (a) orbiter middeck; (b) animal cage being lowered through tunnel connecting middeck and Spacelab; (c) Spacelab; and (d) RAHF.

A winch system, the Module Vertical Access Kit (MVAK), was designed to perform the complicated operation of loading animal cages and personnel from the middeck of the vertically oriented orbiter into the Spacelab below, while on the launch pad (Fig. 4-28).

Mission operation procedures also had to be modified considerably to accommodate animal welfare and life sciences experiment requirements. Late loading of animals into the Spacelab before launch was vital because of animal welfare concerns and because this operation had to be performed during the light phase of the animals' light/dark cycle. Likewise, early removal after landing was necessary in order to conduct postflight studies on the animals before they readapted to Earth gravity.

The main problem that arose during flight was the release of particulates from the animal enclosures into the Spacelab during maintenance operations. Despite the consid-

erable publicity drawn to this problem, postflight analyses showed that neither the crew nor the animals were adversely affected. However, it was recommended that the faulty subsystems be redesigned before flying the hardware a second time. Malfunctions in the leak alarms for the water systems in the primate cages and in three of the rodent cages were also noted. The monkeys' drinking behavior pattern in space set off the leak alarms, pointing to a need for higher leak alarm settings in future missions. Fouling of activity sensors, viewing windows, and temporary restraint systems occurred because of the way in which the animals oriented themselves during waste elimination. No other significant problems were observed in flight, and the hardware was shown to be capable of being flown again after modification.

The orbiter's landing site was changed from KSC to the Dryden Flight Research Facility in Southern California approximately two weeks before the mission. Postflight procedures had to be hastily revised to accommodate this change, but the animals were recovered without incident.

Results

The monkeys and rats were recovered in good condition, healthy and free of microbiological contaminants. Postflight tissue analyses were not performed on the flight monkeys. The flight rats were euthanized a few hours after recovery and their tissues subjected to a variety of tests. Control rats on the ground were euthanized and analyzed in the same manner shortly after. Several changes were noted in the flight animals as compared with ground control animals. These changes are summarized below. Detailed results of science studies are categorized by discipline and described in Appendix 1.

Squirrel Monkeys

Both monkeys ate less food and were less active in flight than on the ground. One monkey adapted quickly to the microgravity condition. The other monkey exhibited symptoms characteristic of Space Adaptation Syndrome, consuming no food and little water during the first four days of flight. On the fifth day of flight, after being hand-fed banana pellets by the crew, its behavior became more comparable to that of the first flight monkey.

Rodents

Some of the changes seen in flight rats, such as absence of interferon production by spleen cells, lower plasma concentration of osteocalcin, and heightened marrow sensitivity to erythropoietin, may have been influenced by the 12-hour period between landing and sample acquisition.

Postflight analyses of rat tissue indicated that the rats had not been exposed to prolonged or significant stress. Growth curves were parallel for all rats. The rats consumed more water during the mission, the circadian rhythm of food intake changed, and body temperature decreased during the animals' active phase.

The rats had decreased muscle tone and muscle mass after flight. There was a shift from aerobic to glycolytic metabolism. More fast- twitch muscles were seen in the rats' soleus muscles after flight. Significant changes were also noted in the bone of the flight rats. Bone mass, and bending and tensile strength were reduced. Bone changes that occurred during this 7-day mission were found to be much greater than the changes noted in tail suspension studies (simulated microgravity studies) conducted for 28 days. Spleen cell production of interferon significantly decreased, which may be indicative of an impaired immune response.

Metabolic changes noted included a shift from a lipid-based to carbohydrate-based metabolism. Changes were seen in brain metabolism and receptors and in the vestibular apparatus. Growth hormone synthesis was decreased. Thymus gland and testes weights were reduced after flight. In cardiac muscle, glycogen and lipid deposition increased and muscle cell microtubules decreased.

In general, the postflight changes noted in rats were similar to the changes observed in humans, and were consistent with the findings of the Soviet Cosmos program.

The life science research objectives of the SL-3 mission were accomplished in no small measure. Operations and procedures developed for mission care of the animals were satisfactory. These included the design modifications made to the RAHFs and the STS to accommodate the payload, the MVAK procedures, late and early access procedures to ensure animal welfare and uncompromised science results, and crew operations within Spacelab. Recovery of healthy unstressed animals demonstrated that the RAHFs were capable of adequately housing and supporting animals in space. The operational experience gained by the personnel involved was expected to be valuable for conducting more complex missions in the future. The amount of data gathered on the physiological, behavioral, and morphological responses of the animals to microgravity surpassed all expectations. The hardware being flight tested was verified from an operational and engineering standpoint and subsystems requiring modifications were identified.

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MISSION PROFILE: STS-51F/Spacelab 2

Mission Duration: 7 days

Date: July 29–August 6, 1985

Life Sciences Research Objectives

To study the effects of microgravity on plant lignification

Life Sciences Investigations [p. 250]

Plant Biology (SL2-1)

Organisms Studied

Pinus elliotti (pine) seedling
Avena sativa (oat) seedling
Vigna radiata (mung bean) seedling

Flight Hardware [pp. 506-507]

Plant Growth Unit (PGU)

Publications [p. 419]

STS-51F/Spacelab 2

The return to Earth of the Space Shuttle Challenger on August 6, 1985, ended the STS-51F mission which had been launched on July 29, 1985. A number of science and engineering tests were conducted with great success on the eight-day mission.

The mission was also called Spacelab 2, even though it was actually the third mission to use the Spacelab facility. The mission had originally been scheduled to fly before Spacelab 3, but it was delayed because a major hardware item had to be redesigned. Spacelab 2 afforded an opportunity for the first engineering tests and scientific application of the instrument pointing system developed by ESA. The remote manipulator system was also employed on the mission, to release and capture a small satellite. The manned Spacelab module was not used on the mission, but the ESA igloo and three instrument-laden pallets were employed. Three other experiments were installed inside the orbiter. A seven-member crew including two payload specialists participated in the mission.

Although the principal objective of the mission was to verify the pallets only mode of the Spacelab and the sophisticated instrument pointing system of the STS, 13 scientific investigations were also conducted. Areas studied were plasma physics, infrared astronomy, high-energy astrophysics, solar physics, atmospheric physics, technology research, and life sciences.

Life Sciences Research Objectives

Two life sciences investigations were conducted aboard the orbiter. One dealt with vitamin D metabolites and bone demineralization in microgravity, and used humans as experimental subjects. The experiment was developed and managed by JSC, and is, therefore, outside the scope of this book. The main objective of the other experiment was to determine the effect of microgravity on lignin production in higher plants. A second objective was to study overall seedling growth and development in space. The investigation was an extension of an earlier study carried out on the STS-3 mission in 1982.

Life Sciences Payload

Organisms

As for the experiment on STS-3, the specimens used for the study were mung bean (*Vigna radiata)*, oat (*Avena sativa*), and pine (*Pinus elliotti*) seedlings. Seedlings were grown in enclosed chambers resembling terrariums. Mung beans were planted in four chambers, oats in two, and pine seedlings in eight. Mung beans and oat seeds were planted 16 hours before launch; germination occurred in space. Pine seedlings were either 4 or 10 days old at launch.

Hardware

The airtight seedling chambers were equipped with temperature probes and gas-sampling ports. Two rows of eight seeds were planted in each chamber, within a synthetic sandwich prepared from a wicking material and spongy foam. An agar matrix at the base of the chamber supplied water and nutrients to the seedlings through the wick. The small plant growth chambers were designed to fit inside two PGUs, each of which contained three plant growth lamps, a timer to provide day/night cycling, temperature sensors, electronically controlled fans, a data acquisition system, and internal batteries. Up to six growth chambers could fit in a PGU. The two PGUs replaced two lockers on the forward bulkhead of the Shuttle middeck. Both PGUs were used in a postflight control experiment after the end of the flight phase of the experiment.

Operations

Preflight activities for the experiment were initiated at KSC 15 days before launch. Activities included planting seeds, assembling the growth chambers, exchanging atmospheric gas in the sealed chambers with a defined gas, photography of the chambers, and loading of chambers into the PGUs.

The launch itself was complicated by several problems which occurred on the launch pad. Because of a main engine failure, the Shuttle employed an orbit about 74 km below the planned 374 km altitude. The lower orbit was disadvantageous to some of the scientific investigations, but the extension of the mission from seven to eight days provided partial compensation.

Little in-flight support of the plant experiment was required. A crew member read and recorded the temperatures of the PGUs,

and checked the equipment two or three times on each flight day. The crew also photographed the plant seedlings and sampled the atmospheric air in the growth chambers.

Upon mission termination, the Shuttle landed at the Dryden Research Facility in California, where a temporary laboratory had been established. The laboratory received the two PGUs two hours after the Shuttle landed. Gas samples were taken from the growth chambers, and the plants were observed and photographed before tissue sectioning and preservation.

An Earth-gravity control experiment was conducted at KSC during the postflight period. PGUs were installed in an environmentally controlled facility for this purpose. The time and temperature profiles of the flight were closely simulated in this experiment.

Results

The quantity and quality of scientific data gathered on the mission was remarkable, particularly in light of the interactive complexity of the scientific program, and the technical difficulties that occurred early in the mission.

It was concluded that plant seeds are able to germinate, and seedlings to grow, in the space environment. Some problems in orientation were noted in mung beans during germination and early growth. Root orientation was somewhat disturbed in oats. Both mung beans and oats exhibited a reduced growth rate. Lignin was significantly reduced in all three species grown in microgravity, providing direct evidence that gravity is an important factor in lignification.

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MISSION PROFILE: STS-34/GHCD

Mission Duration: 5 days

Date: October 18–23, 1989

Life Sciences Research Objectives

To study the concentration and distribution of growth hormone in plants

Life Sciences Investigations [p. 254]

Plant Biology (GHCD-1)

Organisms Studied

Zea mays (corn) seedlings

Flight Hardware [pp. 500-501, 554-555, 504-505]

Passive Freezer
Temperature Recording System-Mod 1:
4-Channel Ambient-Temperature Recorder
Plant Canisters

Publications [p. 420]

STS-34/Growth Hormone and Concentration Distribution (GHCD)

The 5-day STS-34 mission was launched on the Shuttle Atlantis on October 18, 1989 and landed on October 23. ARC-developed payload in the Shuttle middeck was designated Growth Hormone Concentration and Distribution (GHCD).

Life Sciences Objectives

The GHCD was designed to satisfy the requirements of a plant growth experiment. The objective of the experiment was to characterize the effect of microgravity on indoleacetic acid, a plant growth hormone. Ground studies had established that a gravitational stimulus causes rapid hormonal changes in the plant. As indoleacetic acid concentration increases in the lower part of the stem, the stem reorients and grows upward. An understanding of this effect was expected to lead to finding the gravity-detecting device in plants.

Life Sciences Payload

Organisms

Sweet corn (*Zea mays*) seedlings of the Silver Queen variety were used for the experiment. The seedlings were grown in complete darkness for the duration of the flight to eliminate the effects of light on orientation.

Hardware

Four hollow stainless steel canisters were used to hold the seedlings in flight. Twenty-six corn kernels were individually wrapped in filter paper and placed in each of the four canisters. Eight similar canisters were prepared for use in the two ground control experiments.

A battery-operated ambient temperature recorder was located between each pair of canisters. A passive liquid nitrogen freezer was used to freeze the seedlings in two of the flight canisters during the flight.

Operations

Two ground control experiments were carried out in support of the flight experiment. One was conducted at the same time as the flight experiment. The other was conducted postflight to simulate the temperatures experienced by the flight specimens. Specimens in both ground control experiments were frozen after being allowed to grow for the same length of time as the flight specimens.

The seeds were planted in the canisters and kept in total darkness prior to the flight. Water was added to the canisters 17 hours before launch.

On the fifth flight day, a crew member placed two of the flight canisters in the liquid nitrogen freezer to arrest plant growth and to preserve the growth hormone in the plant tissue. The seedlings in these two canisters had a total growth period of 125 hours.

The two unfrozen flight canisters were frozen shortly after the Shuttle landed. The seedlings in these canisters had a growth period of 137 hours.

All specimens were analyzed for growth hormone, cellular structure, lignin, polysaccharides, mRNA, and proteins.

Results

There were no significant chemical perturbations in the seedlings exposed to microgravity. There were almost no differences in indoleacetic acid content in flight and control seedlings. The methods and equipment used in the experiment appeared to be suitable for comparing seedlings exposed to microgravity and terrestrial gravity.

Additional Reading

Schulze, A., et al. Studies on the Growth and Indole-3-Acetic Acid and Abscisic Acid Content of Zea mays Seedlings Grown in Microgravity. *Plant Physiology,* vol. 100, no. 2, 1992, pp. 692–698.

MISSION PROFILE: STS-32/CNCR

Mission Duration: 11 days

Date: January 9–20, 1990

Life Sciences Research Objective

To study circadian rhythms in fungae

Life Sciences Investigations [p. 255]

Regulatory Physiology (CNCR-1)

Organisms Studied

Neurospora crassa (fungus)

Flight Hardware [pp. 522-523, 554-555]

Race Tube Packages
Temperature Recording System-Mod 1:
4-Channel Ambient Temperature Recorder

Publications [p. 420]

STS-32/Characterization of Neurospora Circadian Rhythm (CNCR)

The Space Shuttle Columbia was launched on the STS-32 mission on January 9, 1990. Launch had originally been scheduled for December of the previous year, but problems with the newly refurbished launch pad at KSC resulted in some delays. The mission terminated on January 20, 1990 when Columbia touched down at Edwards Air Force Base.

STS-32's primary objectives were to deploy a satellite, and to retrieve the Long Duration Exposure Facility which had been placed into Earth orbit in 1984. Secondary objectives included the completion of several scientific investigations.

The only ARC payload on the mission was designated Characterization of Neurospora Circadian Rhythms (CNCR).

Life Sciences Research Objectives

The CNCR experiment had previously flown on the STS-9 mission. (The STS-9 experiment was not managed by ARC.) The CNCR payload on STS-32 was designed to determine whether circadian rhythms could persist in the absence of known geophysical and environmental time cues. An internally generated rhythm of about 24 hours regulates many animal and plant processes on Earth. This rhythm may be affected by many environmental factors; stimuli such as light and gravity may be cues for the phenomenon.

Life Sciences Payload

Organisms

The experimental specimen was pink bread mold *(Neurospora crassa*). This filamentous fungus displays a circadian rhythm in the formation of asexual spores, or conidia. The rhythm can be noticed as a pattern because low growing surface mycelia alternate with portions of mycelia containing spore-forming filaments. The rhythm appears to be endogenously generated. The purpose of the experiment was to test this hypothesis and to determine whether *Neurospora* possesses a gravity-sensing system that can affect physiological function. Two strains of the fungus were used. The csp strain has a well-defined rhythm that is not very susceptible to environmental disruptions. The bd strain is less sensitive than the csp to carbon dioxide levels.

Hardware

The experiment package was mounted in a middeck locker in the orbiter. The package consisted of three containers of tubes. The first container had seven race tubes inoculated with the bd strain and eight with the csp strain. The second container had 12 tubes with bd and 13 with csp. The third had five tubes with bd, five with csp. The first and second containers each also had three syringes for gas sampling and a pen for marking growth fronts. The third had an ambient temperature recorder. The race tubes in each container were wrapped with tape. The tubes in the first container were also wrapped with red filters (Fig. 4-29).

Four similar packages were used as synchronous ground controls. These were kept in incubators, in constant darkness, at 25°C and 70 percent humidity.

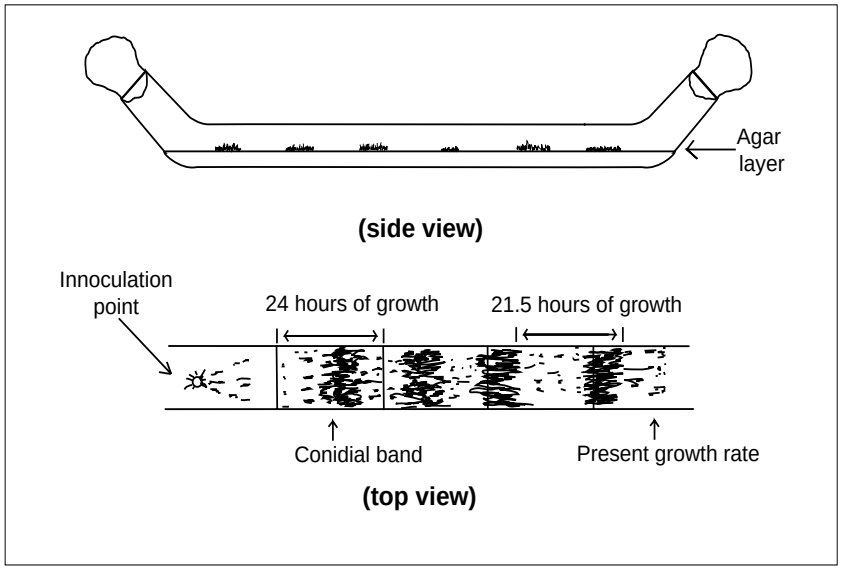

Figure 4-29: Race tube culture.

Other ground control studies were performed postflight to differentiate between effects caused by gravity and those caused by factors related to the environment in the orbiter middeck. The Orbital Environmental Simulator at KSC was used to simulate ambient environmental flight conditions.

Operations

Fungal cultures were grown in constant light during the preflight period, and then trans-

ferred to constant darkness to initiate expression of the rhythm in conidia formation.

A crew member marked the growth front of the fungal culture on the race tubes in the first flight container 10 hours after launch, and on flight days 6, 9, and 10. The red filters enclosing the tubes prevented the cultures from being exposed to light to which the circadian rhythm is sensitive. Growth fronts on the race tubes in the second package were marked in ambient light at the same times as the first package. The tubes in the third package were marked only on flight days 6, 9, and 10. A crew member also sampled the gas in the tubes inside the first and second containers during the flight.

Results

The circadian rhythm of conidiation in *Neurospora* was found to persist in space, with small fluctuations in period and amplitude. There were, however, diurnal oscillations in temperature and carbon dioxide levels on the middeck. The results are suggestive of an endogenously controlled circadian pacemaker whose timing is modified by environmental factors. The data also suggest that *Neurospora* possesses a gravity sensing system that provides input into the pacemaker. Finally, there was evidence of increased growth rate during space flight, which was not dependent on thermally induced acceleration.

Additional Reading

Ferraro, J.S., et al. Biological Clocks in Space: Preliminary Results of STS-32 Middeck Life Science Experiment CNCR-01. *ASGSB Bulletin*, vol. 4, no. 1, 1990, p. 76.

MISSION PROFILE: STS-41/ PSE

Mission Duration: 4 days

Date: October 1–5, 1990

Life Sciences Research Objectives

To study growth hormone deficiency-related changes occurring in microgravity and to determine if growth hormone therapy can ameliorate negative effects

Life Sciences Investigations [p. 256]

Regulatory Physiology (PSE-1)

Organisms Studied

Rattus norvegicus (rat)

Flight Hardware [pp. 460-461]

Animal enclosure module (AEM)

Publications [p. 420-421]

STS-41/Physiological Systems Experiment

The Physiological Systems Experiment was launched on October 1, 1990, on STS-41, a four-day Space Shuttle mission. The experiment was designed by Genentech, Inc., in San Francisco, California and sponsored by the Center for Cell Research at Pennsylvania State University, one of NASA's 16 centers for the Commercial Development of Space. The payload was managed by ARC. The venture between the three groups resulted in the first commercial space research project in the life sciences.

Results of previous studies have indicated that microgravity accelerates reduction in bone calcium, body mass, and immune cell function. A significant reduction in bioactive growth hormone has also been noted in rats undergoing orbital space flight. The collaborative NASA/Pennsylvania State/Genentech project was aimed at extending these findings through a series of flight and ground-based experiments. Besides its potential commercial value, the project was expected to expand medical knowledge regarding the treatment of human bone diseases, organ regeneration and transplantation, and immune and skeletal muscle cell deficiencies.

Early identification of biologically important compounds would likely provide Genentech with a competitive advantage in the marketplace. At the same time, such knowledge would enhance the U.S. position as a biotechnology leader in the international arena. Private business participation is also particularly advantageous for offsetting some space exploration and research costs.

Life Sciences Research Objectives

The objective of the experiment was to test the hypothesis that a growth-hormone-deficient state contributes to bone loss and decreased function of specific tissues in microgravity. The investigators expected that replacement with recombinant growth hormone would retard these changes in the presence of adequate nutrition and exercise.

Life Sciences Payload

Organisms

Sixteen normal adult male rats *(Rattus norvegicus)* were used in the flight study. Each rat was implanted with two osmotic pumps (Fig. 4-30), which delivered controlled amounts of hormones to the animals.

In eight rats, the pumps contained recombinant growth hormone developed by Genentech. The other eight rats served as in-flight controls and were not treated with the recombinant hormone.

Two ground-control experiments were also conducted. Each control group contained eight rats treated with recombinant hormone and eight untreated rats. One control group was maintained under standard laboratory conditions. The other ground control consisted of rats that were maintained in a simulated microgravity condition by using the tail-suspension model.

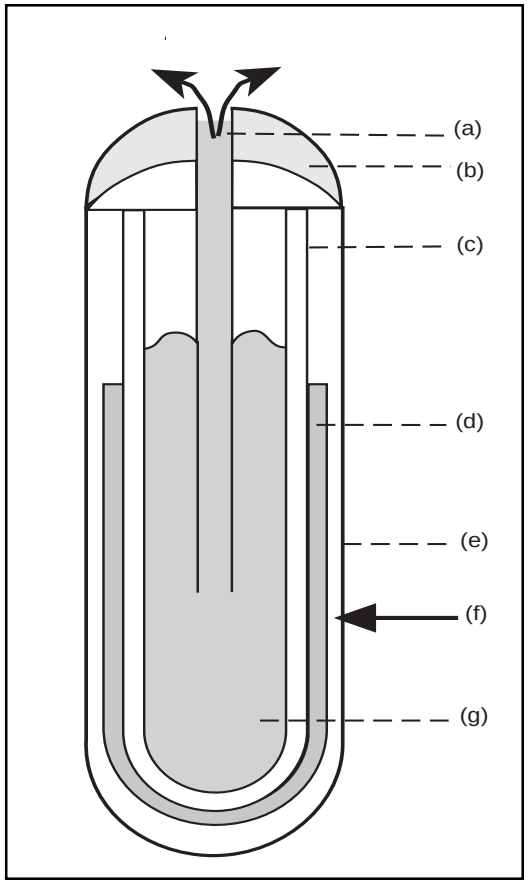

Figure 4-30: The elements of an osmotic pump: (a) drug solution leaving through delivery portal; (b) removable cap; (c) impermeable reservoir wall; (d) osmotic agent; (e) semipermeable membrane; (f) water entering through semipermeable membrane; and (g) reservoir.

Hardware

Rats were housed in two animal enclosure modules (AEMs) provided by ARC. Each AEM could house up to six rats, depending on animal size. The AEM included a stainless steel grid cage module, interior lamps, a water unit, and food bars glued on the cage walls. Fan blowers directed animal wastes into a collection plenum. A layered filter system provided biological isolation between the animals and the crew. Light was provided for 12 hours each day. Osmotic pumps were supplied by Genentech.

Operations

Preflight activities included selection of flight animals and surgeries to implant the osmotic pumps.

No in-flight operations were required except daily monitoring of AEMs and animals by crew members. Environmental parameters in the AEM were automatically

monitored, and food and water were available to the animals on a preprogrammed schedule.

The rats were returned to the investigators' laboratory within a few hours after the Shuttle landed at Edwards Air Force Base in California. They were euthanized approximately five hours after landing. The osmotic pumps were removed. The solutions remaining in the pumps were measured for recombinant growth hormone content. Investigators also performed analyses to assess the function of the pumps.

Results

The flight animals were found to be in excellent condition after the flight. It was concluded that recombinant growth hormone can be preserved for four days, and that osmotic minipumps can successfully deliver the hormone to rats in microgravity. However, an elevated ambient temperature in the Shuttle's middeck may have compromised the experiment's outcome. A series of some 2500 biological measurements and evaluations were conducted by researchers at Genentech and the Center for Cell Research during the postflight period. The results of those investigations cannot be reported here because of their proprietary nature.

Additional Reading

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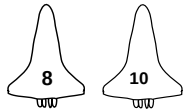

MISSION PROFILE: STS-8/SSIP

Mission Duration: 6 days

Date: August 30–September 5, 1983

Student Investigator: Daniel J. Weber

Corporate Sponsor: Pfizer, Inc., Groton, Connecticut; General Dynamics Convair Division, San Diego, California

Life Sciences Research Objectives

To test performance of the animal enclosure module (AEM)

Life Sciences Investigations [p. 251]

Animal Maintenance (SSIP-8)

Organisms Studied

Rattus norvegicus (rat)

Flight Hardware [pp. 460-461]

Animal enclosure module (AEM) (prototype)

Publications [p. 408]

MISSION PROFILE: STS-10/SSIP

Mission Duration: 8 days

Date: February 3–11, 1984

Student Investigator: Daniel J. Weber

Corporate Sponsor: Pfizer, Inc., Groton, Connecticut; General Dynamics Convair Division, San Diego, California

Life Sciences Research Objectives

To study the gravity-related component in arthritis development

Life Sciences Investigation [p. 252]

Musculoskeletal (SSIP-10)

Organisms Studied

Rattus norvegicus (rat)

Flight Hardware [pp. 460-461]

Animal enclosure module (AEM)

Publications [p. 408]

MISSION PROFILE: STS-29/SSIP

Mission Duration: 5 days

Date: March 13–18, 1989

Student Investigator: Andrew Fras

Corporate Sponsor: Orthopedic Hospital, University of Southern California, Los Angeles, California

Life Sciences Research Objectives

To study the effect of microgravity on bone fracture healing
To study development in microgravity

Life Sciences Investigations [p. 253]

Musculoskeletal (SSIP-29)

Organisms Studied

Rattus norvegicus (rat)

Flight Hardware [pp. 460-461]

Animal enclosure module (AEM)

Publications [p. 420]

Student Shuttle Involvement Program (STS-8, STS-10, and STS-29)

The Shuttle Student Involvement Program (SSIP) is sponsored jointly by the National Science Teacher's Association and NASA. The program gives students in U.S. secondary schools the opportunity to propose experiments for flight on the Space Shuttle. A contest is held every year to select experiments for flight. Each experiment is sponsored by an individual or organization in the private sector.

ARC has been involved in three SSIP life sciences experiments. These were flown on STS-8, STS-10, and STS-29.

Missions

STS-8

The six-day STS-8 mission was launched on August 30, 1983. The performance of the AEM was tested during the flight. The AEM had been built for an SSIP experiment that was to be flown on STS-10, and it had to be tested during space flight to ensure that the experiment's objectives could be achieved.

Six gnotobiotic Lewis Wistar rats were used as test subjects. Because the microbial flora found in the rats were known, the investigator hoped to determine if the AEM was able to contain microorganisms without leaking into the environment outside the AEM. By the same rationale, it was expected that it would be possible to determine whether microbes from the crew had leaked

into the AEM and contaminated the rats. Control studies were performed on the ground using identical groups of rats.

Preflight and postflight cultures were made of the bacterial flora found in the animals, the AEM, and the food and water sources. The AEM was shown to be capable of maintaining the rats in good health. Two microorganisms were found in the animals postflight that had not been present preflight. These were presumably introduced by the potatoes that had been provided as a food and water source. An alternative explanation was that the AEM had not been properly sterilized preflight. Since the microorganisms were not found in the exhaust system of the AEM, it was concluded that the AEM was able to maintain biological material in isolation.

STS-10

The STS-10 SSIP experiment was conducted on an eight-day mission that began on February 3, 1984. Two corporate sponsors were involved in the experiment because of its complex nature. General Dynamics designed and developed the animal housing unit, and Pfizer, Inc., helped the student investigator to define the science aspects of the experiment. The objective of the experiment was to test the hypothesis that development of arthritis has a gravity-related component.

Six rats were used in the flight experiment. Three of the rats were healthy. The other three were injected with complete Freund's adjuvant, which stimulates an arthritic response that has many characteristics in common with human rheumatoid arthritis.

The spread of the disease was less extensive in flight rats than in the ground controls, indicating that lowered gravity conditions may have been beneficial.

STS-29

The five-day STS-29 mission, which occurred from March 13-18, 1989, flew two SSIP life sciences experiments. Only one of these was developed by ARC. Its objective was to study the effects of weightlessness on the healing of bone fractures. Four specific pathogen-free Long Evans rats with bone fractures were flown inside an AEM. A microgravity rodent bottle provided water for the rats. Tissues from flight rats, ground controls, and tail-suspension controls (simulated microgravity) were examined postflight by light and electron microscopy. Results indicated that healing of fractures is delayed in rats maintained in actual and simulated microgravity.

Additional Reading

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Marshall, G.J., A.I. Fras, M.E. Kirchen, J.R. Sweeney, K.M. O'Connor, and S.J. Stover. Microgravity vs. Weight Bearing vs. Gravity Suspension: Systemic Effects in the Rat. *ASGSB Bulletin,* vol. 5, no. 1, D-11, October 1991, p. 29.

NASA. *Shuttle Student Involvement Project Experiment Integration Plan*. JSC-17990, June 1988.

NASA. *Launch and Land Your Experiment.* Student Guide, NSTA-NASA Space Shuttle Student Involvement Program, unpublished report.

STS Missions After 1990

Several STS missions with ARC-developed life sciences experiments were flown between 1990 and the completion of this book in June 1994. These missions are briefly introduced here, and include dedicated Spacelab missions and experiments flown in the Shuttle middeck.

Spacelab Missions

The STS-40 mission launched in June 1991 was the first Space Shuttle mission to be dedicated to life sciences research in space. The payload was termed Spacelab Life Sciences-1 or SLS-1. Investigators from several countries conducted experiments on crew members, rats, jellyfish, and cells. Investigators from the U.S.S.R. were invited to participate in response to the many opportunities provided through the Cosmos Program (see page 118). In addition, tissue samples were also received by investigators from Canada, France, Germany, and Australia.

The general objectives of the SLS-1 investigations were to understand some acute and longer-term responses of living organisms to the space environment, and to help define adequate physiological and performance countermeasures for humans in space. The responses of the cardiovascular, renal/endocrine, circulatory, immune, musculoskeletal, and neurovestibular systems to the microgravity environment were studied. Equipment essential for later life science missions was tested on SLS-1. Included were a redesigned RAHF, an instrument for measuring mass, a refrigerator/incubator module, a general purpose work station and a transfer unit.

The SLS-2 payload, launched in October 1993 as STS-58, repeated and expanded some of the studies that were conducted on the SLS-1 mission. General research objectives included investigations regarding bone growth, muscle atrophy, hematology, and vestibular functions. Two RAHFs housed a total of 48 rodents, the largest animal payload to date. For the first time on SLS-2, blood draws and tissue dissections were conducted in space, allowing investigators to further differentiate microgravity effects from those associated with landing and re-adaptation to Earth gravity. For in-fight manipulation of the animals, a rodent cage was inserted into the general purpose transfer unit and carried to the general purpose work station, where the rodents were removed by payload specialists. Special equipment was developed to facilitate animal operations in the absence of gravity.

While investigators for SLS-1 were required to share research subjects, for SLS-2 each of the primary U.S. investigators had their own group of rodents, which allowed each investigator to design their own collection protocol. Investigators from Russia, Japan, and France also received tissue samples. The highly successful flight of SLS-2 represents the culmination of many years of effort in developing a high-quality scientific facility for STS and future Space Station experiments.

The International Microgravity Laboratory-1 (IML-1) payload was launched on the STS-42 mission in January 1992. It carried a

diverse range of life sciences and microgravity science experiments from NASA, the ESA, Japan, and Canada. The major pieces of hardware used were the ESA Biorack and the NASA funded, investigator-developed Gravatational Plant Physiology Facility. Several experimental subjects including plants, roundworms, mouse cells and yeast were used in the studies sponsored by ARC.

Japan leased the Spacelab for the STS-47 mission flown in September 1992. The payload, known as Spacelab J, contained some joint investigations with the U.S. ARC sponsored a major experiment to study development in frogs, employing the Frog Embryology Unit, developed and built by ARC. The payload specialist for the mission was the first Japanese astronaut flown on the STS.

Middeck Experiments

The STS-46 mission in July 1992 flew an ARC-sponsored experiment that was designated Pituitary Growth Hormone Cell Function. Cultures of rat pituitary cells were flown onboard the Shuttle to study the effect of space flight on growth hormone production, storage, and secretion.

A Shuttle middeck experiment, the Physiological Systems Experiment (PSE-01), was flown on the STS-41 mission in October 1990. Its objective was to study the effect of space flight on rats. Three additional PSE middeck experiments have been flown on Shuttle flights: (PSE-02) on STS-52 in October 1992, (PSE-03) on STS-57 in June 1993, and (PSE-04) on STS-62 in April 1994. The primary objective of PSE-04 was to study the relationship between the immune and skeletal systems during exposure of rat subjects to microgravity.

A series of three Shuttle middeck experiments, termed Physiological Anatomical Rodent Experiments (PARE), were flown on STS missions in 1991 and early 1993. These were STS-48 (PARE-01) in September 1991, STS-54 (PARE-02) in January 1993, and STS-56 (PARE-03) in April 1993. These experiments were designed to investigate the effects of space flight on bone and muscle in rats.

In February 1994, the Immune-01 flew on STS-60 in the SpaceHab module. The payload was a commercial experiment that measured the immune response of tissue and body fluids of normal rats to microgravity.

In April 1994, a new experiment designated Space Tissue Loss (STL) flew on the middeck of STS-59. The purpose of the experiment was to test the ability of the STL tissue culture module, designed by the Walter Reed Army Institute of Research, to function in flight. The experiments involved the study of the effects of flight on two cell lines (cardiac and bone) of immunologic importance.

The Cosmos Biosatellite Program

The Soviet/Russian series of Cosmos satellite missions is carried out for a variety of military and civil purposes. Falling under its jurisdiction is the Cosmos biosatellite program, which includes a series of missions dedicated to biological experimentation in unmanned, Earth-orbiting satellites. The Cosmos biosatellite program is often referred to as the Biocosmos program or the Bion program by various non-U.S. sources.

Program Overview

The Russian biosatellite program began with the launch in 1966 of Cosmos 110, a mission concerned mainly with studies of the cardiovascular system. The 22-day Cosmos 110 mission is the longest duration biosatellite orbital flight achieved to date. A wide variety of experimental subjects was flown on subsequent missions, including rats, beginning with Cosmos 605 (also called Bion 1), and primates, beginning with Cosmos 1514.

The unparalleled success of the Cosmos biosatellite program is due to several factors. The research conducted under its auspices is complex, combining studies in numerous areas within the life sciences. Many organisms from very different taxonomic orders have been studied on biosatellites since the program's inception. An important feature of the program has been its predictable, frequent launch schedule. Its continuous internal evolution has enabled scientists to study increasingly complicated levels of a given problem. The participation in the program of specialists from a number of European countries and the U.S. has also been to its advantage.

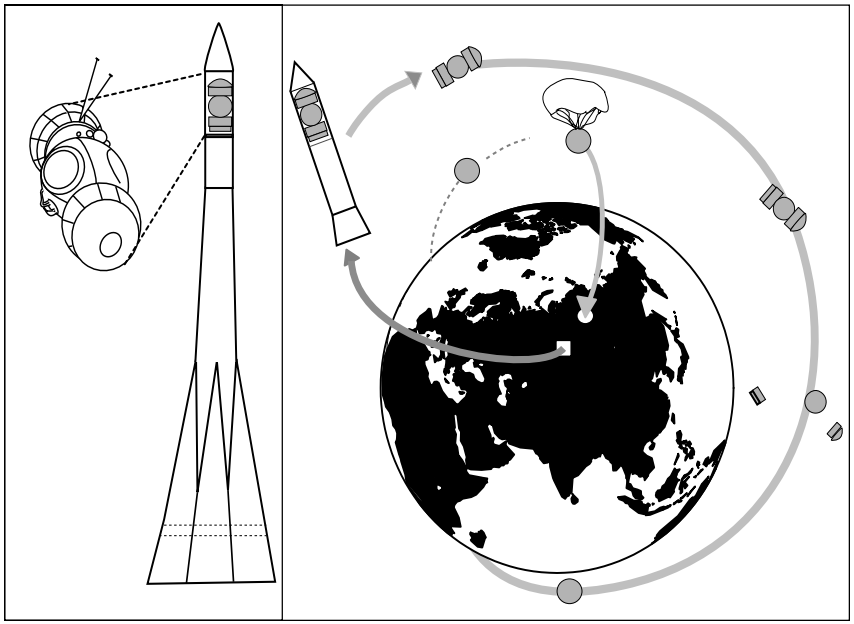

Figure 4-31: Launch and recovery of Cosmos missions with U.S. participation.

Cooperation in space ventures between the U.S.S.R. and the U.S. was initiated in 1971, with the signing of the U.S./U.S.S.R. Science and Applications Agreement (which included an agreement on space research cooperation). The the U.S.S.R. first offered to fly U.S. experiments on a Cosmos biosatellite in 1974, only a few years after the termination (in 1969) of the U.S. biosatellite program. The offer was realized in 1975 when the first joint

U.S./U.S.S.R. investigations were carried out on the Cosmos 782 mission.

Through 1990, the U.S. participated in seven Cosmos biosatellite missions: Cosmos 782, 936, 1129, 1514, 1667, 1887, and 2044. Each mission is described in detail in later sections of this chapter. An eighth joint mission, Cosmos 2229, was launched in 1992. Funds furnished by the U.S. were used for experiment development and analysis, mission logistics, and project management for U.S.-related mission activities. All costs related to launch have been borne by the U.S.S.R. The Institute of Biomedical Problems of the U.S.S.R. Ministry of Health in Moscow has played a leading role in research design, experiment integration, and data interpretation. The primary responsibility for equipment design has been undertaken by the Biophyspribor Design Bureau in Leningrad (St. Petersburg). Soviet scientists provided all organisms flown on these missions. The only exception to this was on Cosmos 782 when U.S. scientists provided some specimens.

On the three earliest of the joint U.S./U.S.S.R. missions, most U.S. experiments were conducted in carry-on packages. Such packages typically contained insects or plant tissues and required only the use of the spacecraft environmental control and life support systems. Radiation dosimetry experiments of the carry-on type were also developed by U.S. investigators for these missions. Other U.S. experiments involved obtaining preflight and postflight measurements from rats flown on the biosatellites.

A new level of cooperation between the two countries began with the Cosmos 1514 mission. On this and subsequent missions, the U.S. provided experiment hardware that required integration with the Soviet spacecraft and data systems.

Since Cosmos missions typically remained in orbit for a considerably longer time than the U.S. Space Shuttle, the Cosmos biosatellite was particularly useful for studies requiring longer exposure of biological subjects to microgravity. Joint U.S./U.S.S.R. Cosmos flights have served as testing grounds for developing U.S. experiments and flight hardware. Experience acquired by U.S. scientists and engineers on these missions will be a valuable asset for developing U.S. space programs such as the STS Extended Duration Orbiter and Space Station.

The goals of the joint U.S./U.S.S.R. research performed within the Cosmos biosatellite program are to: investigate mechanisms for physiological, biochemical and behavioral changes associated with the space environment; identify and evaluate potential hazards to man during long-duration space flight; study ways of supporting long-duration manned space flight in the areas of artificial gravity, radiation shielding and life-support; and use the microgravity environment to determine the role of gravity in terrestrial biological phenomena.

The Cosmos Biosatellite

The biosatellite is designed for conducting long-term experiments in space and for returning the biological subjects to Earth. It is composed of three compartments: the landing module, the instrument assembly compartment, and a hermetically sealed unit that contains additional chemical sources of energy (Fig. 4-32).

Joseph Sharp

Joseph Sharp received his B.S., M.S., and Ph.D. in psychology/neuroanatomy from the University of Utah. In 1961, he began his career as a research psychologist at the Walter Reed Army Institute of Research where, in 1970, he was appointed Deputy Director of Neuropsychiatry. He has also served as Chief of the Department of Experimental Psychology and Behavioral Radiology at Walter Reed, and in 1969 and 1970, was Deputy Commissioner of Public Health for the State of New York. He came to ARC in 1974, and the last five of those years, served as Director of Space Research at Ames. Currently he is with the College of Science at the University of Utah, Cedar City, Utah.

In 1974, soon after he joined ARC, he attended a U.S./U.S.S.R. Joint Working Group meeting in Tashkent, U.S.S.R., with the Director of Life Sciences at NASA Headquarters, David Winter. "That was when the Russians, unannounced, dropped the offer on us to fly U.S. experiments on the Cosmos series," he recalled. "There had been zero preparation for that back in the States. Dave didn't know whether he had the authority to accept the offer, whether he had the budget, and what the scope was. I can remember walking for hours in the garden near the meeting place, discussing the offer. We finally talked ourselves into it, and Dave accepted. I was responsible for putting people and experiments together back at Ames. The time to launch was very short. We didn't even know what quality to build our equipment to." Finally, it was decided that Apollo-Soyuz quality standards would be used.

"Getting that first series of experiments on Cosmos was really tough stuff," Sharp said. Some of the experiments had to be simplified, to have them ready in time for flight. "But that first series started a process that continues to this day. The vitality of the program is shown by the fact that it has survived for so long, even during the Reagan era. All the joint Nixon-Breszhnev programs were killed during that period, except for the Cosmos flight program. The agreement was signed before Reagan took office, and he honored it. So we carried on through that time, with reasonably good communications. At that time experiment complexity was increasing, so there was more and more dialogue going on between the two countries. Of course, everything had to be blessed by the National Security Council." The intelligence agencies also monitored the Cosmos activities, though indirectly. "We didn't do some of the things we wanted to do," Sharp said, "because of technology transfer concerns."

Cosmos has evolved over the years. "Things have gotten more bureaucratized," Sharp explained. "But the Program has also become more productive. Experiments are more complex now. There are more collaborations between scientists. I think more Soviet scientists have been brought into their space program because of this than would have otherwise. And in our country, there are now many scientists who have collaborated with the Soviets."

The Cosmos program brought NASA into direct contact with French and other European life scientists. This contact led to several collaborative projects. The early Cosmos flights served as a catalyst to bringing Ames into the modern era of flight programs. "When I arrived at Ames, there was no real life sciences flight program although good science was being done," Sharp says. "The U.S. biosatellite program had withered by the mid '70s. Cosmos really allowed us to organize to do the Shuttle flights."

Sharp attributes much of the Cosmos program's success to Oleg Gazenko, the now retired Director of the Institute of Biomedical Problems in Moscow. "He kept it all together," Sharp says. Although he now acts in an advisory role, Gazenko's influence on the Soviet space program is still strong (see interview, page 148).

David Winter

David Winter is a physician/neurophysiologist by training. He served as the Deputy Director of Life Sciences at ARC from 1971 to 1974 and as the NASA Director for Life Sciences at NASA Headquarters from 1974 to 1979. Between 1974 and 1992, he worked at the Sandoz Pharmaceuticals Corporation. He is presently the President and Chief Operating Officer of GenPharm International, a biotechnology company based in California.

As the NASA Director of Life Sciences, David Winter was the co-chair of the U.S/U.S.S.R. Joint Working Group on Space Biology and Medicine. He was instrumental in bringing about U.S. participation in the Cosmos program. The U.S.S.R. first offered to fly U.S. experiments on the Cosmos biosatellite during a joint U.S./U.S.S.R. meeting in Tashkent in 1974, at which Winter was present. "The offer was such a unique opportunity," he said. "How could we have refused?" Because the time interval between the Soviet offer and Cosmos 782 (the next scheduled biosatellite flight) was short, preparing the U.S. experiments for flight was difficult. "We had to move quickly," Winter recalled. "People worked hard. Having an endpoint that you could see made it easier. You knew you had to make that launch date."

Winter believes that the Soviet offer was motivated by a very genuine interest in extending the cooperation from manned flight to space biology. "There were these two superpowers, each with their own agendas, each wanting to succeed, and to get more publicity than the other. It was a competition. But the one thing both sides felt very keenly about was that nobody wanted a disaster. Pooling together resources and information was the one way to make the most of what each side had. Our experiments had a small number of subjects, and so did theirs. So we put them together." Pooling information was complicated by the fact that the two countries used different research methods. "In the very early stages of the Joint Working Group, we spent a great deal of time standardizing procedures for manned space flight," Winter explained. "They used one system, we used another. For example, they were using air columns to determine blood pressure, and we were using mercury columns. Standardizing was very pedestrian work, but it had to be done in order to compare results." One reason that different methods were used was that Soviet technology was not as sophisticated at that time as U.S. technology. "They would use a simple system, not intellectually simple, but mechanically so, and just keep pushing it to the limits. They worked harder, and got more out of it than we did."

Winter was a member of the Joint Working Group for eight years. Like many of the other participants, Winter was struck by the trust that was built up between the two sides. "We had a very good relationship with the Soviets," he said. "There wasn't a lot of foolishness. We just did what we had to do, and they did what they had to do. We were not sparring." Cooperation on the Cosmos program was not the only result of the Joint Working Group. "We not only negotiated the whole Cosmos thing, but also the Soviets coming onboard the Shuttle. That was negotiated back in 1977 or 1978. It has taken a long time to happen."

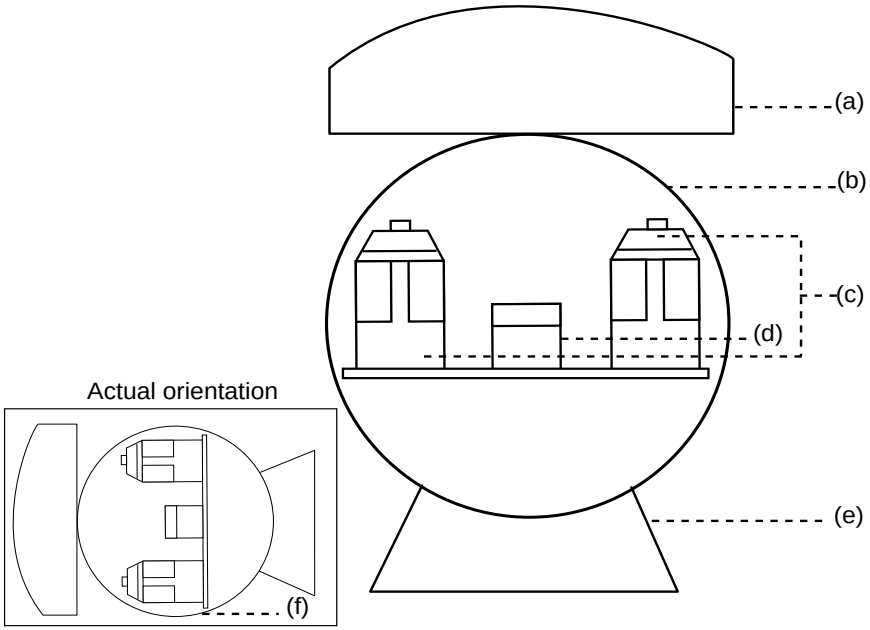

Figure 4-32: Cross section of Cosmos biosatellite: (a) instrument assembly compartment; (b) landing module; (c) monkey capsule; (d) rodent capsule; (e) energy storage unit; and (f) actual orientation just after landing.

Mission	*Specimens Flown*	*Duration*	*Year*
782 1975	25 rats, fruit flies, carrot tissues and cells, fish embryos	20 days	
936 1977	30 male rats, fruit flies	19 days	
1129 1979	32 male rats, 5 female rats, quail eggs, carrot tissues and cells	19 days	
1514	2 rhesus monkeys, 10 female rats	5 days	1983
1667	2 rhesus monkeys	7 days	1985
1887 1987	2 rhesus monkeys, 10 male rats	13 days	

Table 4-4: Organisms used in U.S. experiments onboard Cosmos biosatellites.

The landing module is a complex, autonomous compartment capable of housing the biological subjects. It has a modified Vostok design, similar to the spacecraft used in early Soviet manned space flights. Spherical in shape, with a diameter of approximately 2.5 m and a gross weight of about 2250 kg, it can accommodate a 900 kg payload. Batteries supply power required during the flight. The interior of the spacecraft is maintained at sea level conditions, with a total pressure of approximately 760 ml mercury, an oxygen partial pressure of 135-212 ml and a carbon dioxide partial pressure of up to 7 ml. Relative humidity is approximately 56–66 percent during flight, and ambient temperatures range from 22.0° to 25.5°C. Ammonia, methane and other gaseous impurities generated within the craft are kept at low levels by circulating the cabin air through canisters of absorbent materials.

Eugeny Ilyin

Eugeny Ilyin graduated from the Military Medical Academy in Leningrad in 1961. From 1961 to 1964, he was a senior researcher in the Institute of Aviation and Space Medicine, a part of the U.S.S.R. Air Force. In 1964, he joined the Institute of Biomedical Problems in Moscow. He is now an M.D. and a Professor of Aviation, Space and Naval Medicine. His area of scientific interest is human and animal physiology in space and extreme environments. Ilyin is a member of the International Academy of Astronautics subcommittee on Space Planetary Biology and Biophysics, and the Center on Space Research subcommittee on Gravitational Biology.

Ilyin was among a group of Soviet physicians selected to be cosmonauts to conduct in-flight animal experiments. The Voskhod manned space program was to be his door into space. He never experienced a space flight because the Voskhod program was discontinued after only two of its five scheduled flights had been completed. "However, we didn't lose heart," Ilyin said. "Termination of that project stimulated a different program of animal research onboard unmanned space vehicles."

In 1966, Ilyin participated in the Cosmos biosatellite program for the first time, preparing experiments on canine subjects for the Cosmos 110 flight. In 1970, he was appointed as the Director of the Program, and has served in that capacity since then. His longtime experience with animal experiments, and his introduction to the space experience through Voskhod, helped him meet the challenge on the Cosmos biosatellites. "On the basis of experience, I can assert that experiment preparation alone takes much time and is a very challenging job. We have to select animals, examine them thoroughly, train them to use a feeder and a water dispenser in the absence of man, so that we can study behavioral patterns, central nervous system activity, and complex motor reflexes. This is really very difficult." Ensuring that the life support system and the experimental hardware function perfectly is no less a challenge. "We have to design, develop, and test the equipment many, many times. It's a huge responsibility, because the biosatellite and the experiments flown cost millions and millions of rubles."

Animal experiments in space are necessary because they furnish data that cannot be obtained from humans due to methodological or ethical considerations. "We need this information to design and develop methods to protect humans from the deleterious effects of the space environment," said Ilyin. The safety of the animals is of great concern to Ilyin and his colleagues, and not only because of the data they provide. "Our lesser brothers, with whom we spent a lot of time during experiment preparations, became very close and very dear to us," he explained.

Ilyin's team has surmounted many obstacles during Cosmos biosatellite flights. "We've had oxygen increases in the space cabin, rising temperatures, breakage of wires from electrodes implanted in animals, failures in telemetry communications links with the biosatellite, and so on. But what matters is that our work was not futile. We have a lot of very valuable data."

Ilyin is particularly proud of the cooperative interaction between his team and U.S. scientists. "The NASA Ames Research Center is the largest and most important partner in our program," he said. "Our joint efforts have been very successful. I dream of the day when we'll be able to launch an international biomedical laboratory carrying physicians and biologists from different countries who will perform experiments on both animals and humans. But for now we have to continue to fly animal experiments on unmanned vehicles as well as on manned ones, since they both have unique advantages."

The biosatellite is launched from the Plesetsk cosmodrome, on the Cosmos launcher. The B1 version of the launcher used between 1962 and 1972 was capable of placing 280 to 600 kg in low Earth orbit. After almost 150 successful missions, it was replaced by the C version. Based on a medium range ballistic missile, the C launcher has a reignitable second stage and is able to reach very high orbits.

Additional Reading

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MISSION PROFILE: Cosmos 782

Mission Duration: 20 days

Date: November 25–December 15, 1975

Life Sciences Research Objectives (U.S.)

To compare the effects of microgravity and artificial gravity on genetics, growth, development and aging of biological systems
To measure radiation levels in space

Life Sciences Investigations (U.S.) [pp .259-276]

Cell/Developmental Biology (C782-1, 2)
Immunology/Microbiology (C782-3.1, 3.2)
Musculoskeletal (C782-4.1, 4.2, 5, 6)
Plant Biology (C782-7, 8.1, 8.2, 8.3, 8.4)
Radiation/Environmental Health (C782-9, 10)
Regulatory Physiology (C782-11, 12, 13)

Organisms Studied (U.S.)

Rattus norvegicus (rat)
Drosophila melanogaster (fruit fly)
Fundulus heteroclitus (killifish) eggs
Daucus carota var. carota (carrot) tissue and cells

Flight Hardware (U.S.) [pp. 476-477, 524-525]

Carrot Embryoid Container
Carrot Tumor Growth Container I
Radiation detectors
U.S.S.R.-provided—see Appendix 3

Publications [pp. 421-425]

Cosmos 782

The Cosmos 782 mission marked the first time that the U.S. participated in the Soviet Cosmos program. Launched from Plesetsk on November 25, 1975, the Cosmos 782 biosatellite was recovered in Siberia on December 15. Various physics and biology experiments were flown on the 20 day mission. Scientists from France, Czechoslovakia, Hungary, Poland, Romania, the U.S., and the U.S.S.R. participated in these investigations.

More than 20 different species were flown on the mission. U.S. investigators conducted experiments on a subset that included rats, fruit flies, carrot tissue and cells, and fish eggs. A U.S. radiation dosimeter experiment was also carried out without using biological materials.

A centrifuge on the spacecraft created an artificial 1 g environment for some of the biological subjects. Specimens rotated on the centrifuge were compared with specimens maintained in microgravity conditions.

U.S. Life Sciences Research Objectives

The general objective of the U.S. life sciences experiments was to compare the effects of microgravity and artificial gravity on the genetics, growth, development, and aging of biological systems. Aging processes were studied using fruit flies as experimental subjects. The effects of microgravity, artificial gravity, and the randomized gravity vector of a ground-based clinostat were studied on carrot tumor growth. Another experiment using cultured carrot

Lyuba Serova

Lyuba Serova studied at Moscow University and is now affiliated with the Institute of Biomedical Problems in Moscow. Her specialty is developmental biology.

A pioneering researcher in Space Life Sciences, Serova has participated in the Cosmos Biosatellite program for more than two decades. Having worked with people from many different countries, she realizes the difficulties inherent in uniting the efforts of diverse researchers. She says that this makes her feel like a citizen of the world. "All these people are so different, and yet we have so much in common, and we're all working for the common good. Somehow, it gives you a better understanding of your own strengths and weaknesses." The mutual trust that has developed between the U.S. and Soviet Cosmos teams is one reason the program has been so fruitful. That also required a recognition of their differences, according to Serova. "During the preparation for the first cooperative Cosmos mission, one of the American scientists came to the U.S.S.R. He demonstrated various pieces of equipment, and he used to ask me, 'Do you have things like this?' Or, 'We normally discard this stuff. What about you?' Later, I took him to the Kremlin, and I showed him all the beautiful things in Moscow, and asked him, 'And do you have such things?' And he said 'Well, the U.S. is a young country, so we don't have things like that.'"

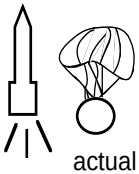
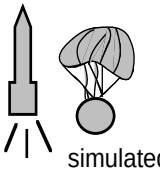
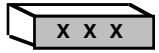
Serova notes that common research interests have formed a bond between the U.S. and Soviet scientists. She recalls planning the developmental biology experiment for the Cosmos 1514 mission with Jeffrey Alberts, her American counterpart. "We tried to agree on how to share biosamples if only one of the pregnant rats onboard gave birth. I really treasure those long days of cooperative effort." She also remembers discussing the results of the Cosmos 1129 mission with Richard Keefe, a U.S. scientist. "He said 'these biosamples and these data, they are not mine or yours. They belong to all the people on the Earth.' I think it's attitudes like this that unite people more than anything else."

cells studied the development process in higher plants. A follow-up to an Apollo-Soyuz experiment was conducted to explore the harmful effects of microgravity on growth and development in fish eggs. This experiment was the only joint U.S./U.S.S.R. study flown on the Cosmos series of biosatellites that was developed by JSC; all others were developed and managed by ARC. Rat experiments were designed to assess microgravity effects on gastrointestinal, endocrine and lymphoid systems and on blood, muscle, bone, and eye tissue. A radiation dosimetry experiment measured the high-linear-energy-transfer (LET) particle radiation aboard the biosatellite.

U.S. Life Sciences Payload

Organisms

Twenty-five unrestrained male Wistar rats (*Rattus norvegicus*) were flown aboard the spacecraft in individual cages. Body temperature telemetry transmitters were implanted in five of the rats. Two

	Flight	Synchronous Control	Vivarium Control
Number of rats	25	25	25
Launch/recovery stress *• noise* *• vibration* *• acceleration*	 actual	 simulated	none
*Food available**	40 grams/ animal/day	40 grams/ animal/day	40 grams/ animal/day
Housing	 individual cages	 individual cages	 caged in groups of 3-4
Environment *• temperature* *• humidity* *• lighting, etc.*	 spacecraft conditions	 simulated spacecraft conditions	standard laboratory conditions
Gravitational force	microgravity	1 g	1 g

**Amount consumed may actually be less.*
Table 4-5: Cosmos 782 flight and control rat experiments.

control groups of rats were studied on the ground—the synchronous control group and the vivarium control group, discussed in detail below.

Studies on growth and development provided by U.S. specialists were conducted on 1000 embryos of *Fundulus heteroclitus*, a small shallow water minnow (Walbaum) of the Beaufort, North Carolina, strain. Embryos of five different age groups were used in the experiments. One hundred flight embryos from each age group were subjected to artificial gravity, and an identical flight group exposed to weightlessness. Four different control studies were conducted on the ground to support this experiment.

Other experimental subjects included a Domodedovo-32 strain of the fruit fly *Drosophila melanogaster*, carrot (*Daucus carota*) tissue (provided by U.S. specialists) and cultured carrot cells.

Hardware

U.S.S.R.-Provided

Experimental materials were arranged in three tiers inside the spacecraft (Fig. 4-33). The upper platform was a centrifuge which was set to rotate at a constant speed of 52 rpm. Containers with fruit flies, *Fundulus* embryos, carrot tissue, and cultured carrot cells were placed on this platform. They received a 1.0 g or 0.6 g force, depending on their position on the centrifuge. A stationary lower platform held materials identical to those on the upper platform. Twenty-five rats in individual cages occupied the space below the lower platform.

Each cage consisted of two intercommunicating cylinders (Fig. 4-34). Each had a diameter of about 9.5 cm and was about 20.8 cm long. The upper cylinder housed the rat, while the lower one served as a waste collection trap. Cabin air circulated through the cages and was returned, via the lower cylinder, to the cabin after being passed through an activated charcoal filter. The upper animal

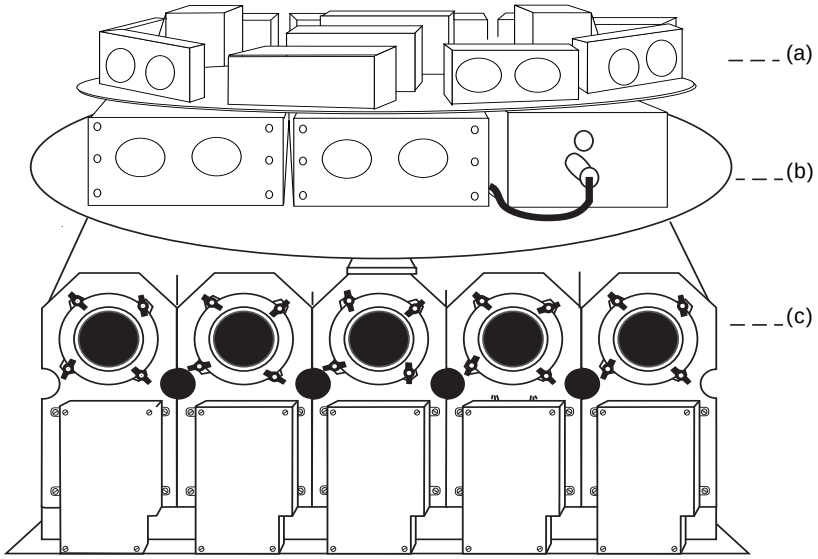


Figure 4-33: Arrangement of experimental materials in the Cosmos 782 biosatellite: (a) Tier 1: centrifuge with fruit flies, fish embryos, and carrot tissue/cells that could receive a force of 1 g or 0.6 g; (b) Tier 2: stationary platform with same specimens as on centrifuge; (c) Tier 3: rat cages.

chamber was furnished with light on a 12:12 light and dark cycle. An automatic watering system provided water freely to the animal. A feeder cup dispensed 10 grams of paste food every 6 hours. A circular coil surrounding the cage monitored physical activity. Cages were arranged in groups of five and a common food and water reservoir used for each group.

Fish embryos were housed inside a two-chambered aluminum case. Each chamber contained five flattened polyethylene bags separated by thin perforated foam. Embryos were suspended in artificial sea water inside the polyethylene bags.

Fruit flies were maintained in standard cotton-stoppered vials placed in sheet metal flight containers. Standard food medium was provided.

U.S.-Provided

Carrot tissue for the tumor growth experiment was contained in cylindrical acrylic canisters, each about 8.5 cm in diameter and about 10.5 cm in height. There was a stack of three dishes in each canister. The dishes were held together by a metal rod which passed through a hole in the center of each dish. Carrot slices were placed in four holes surrounding the central hole of each dish. The canisters were sealed with anodized aluminum caps which included filters and holes for the passage of air.

The carrot development experiment was also housed in acrylic canisters. Each canister consisted of a tube with two end caps and two filters for air, a thermometer, a foam pad, nine petri dishes and a four-legged standoff cushion. Each of the petri dishes contained clones of carrot cells in shallow agar medium.

Radiation detectors were made of cellulose nitrate and Lexan polycarbonate photographic films. High-LET particle flux and integral LET spectrum were measured by thin detector packages, each consisting of seven thin plastic films held together with tape. Aluminized mylar wrapping protected the films

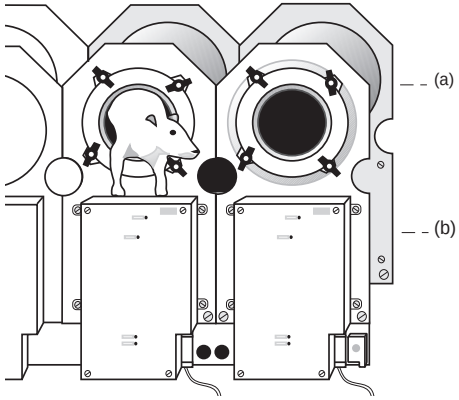


Figure 4-34: Rat cages consisting of (a) cylinder for housing rat; and (b) waste collection trap.

from exposure to ultraviolet irradiation. Thick detector packages, each consisting of 75 plastic films, measured charge spectrum.

Operations

Two kinds of ground control experiments aided in interpreting in-flight data. The synchronous ground control experiment was initiated 5 days after launch. Experiments identical to the flight experiments were carried out in a spacecraft mock-up. The environmental conditions of the spacecraft were also duplicated. The centrifuge used as a control for the in-flight centrifuge rotated at the same speed as during flight, but gravitational forces on the ground resulted in a greater centrifugal force. Launch stresses were also simulated during the synchronous control study. The vivarium control experiment, begun at the time of launch, provided data on minimally stressed specimens. Environmental conditions for this experiment were like those in a standard laboratory.

The U.S.S.R. supplied rats and fruit flies. The U.S. investigators provided specimens for other U.S. experiments. Several treatments had to be performed on the three experimental groups before the experiments began. In the case of the rat experiments, injections, changes in diet, and cage training needed to be carried out.

Onboard sensors gathered housekeeping data during the flight. Information on rat body temperature and motor activity was telemetered to the ground.

Biological materials needed to be retrieved within six hours after the biosatellite landed. Equipment and a team of engineers and scientists were airlifted to the recovery site to conduct the necessary procedures. A field laboratory was set up in insulated tents (Fig. 4-35). Electrical power was supplied by two portable generators. A temperature of 18-22°C was maintained within the laboratory, an extraordinary accomplishment in a Siberian winter.

Within 11 hours of recovery, 12 of the 25 flown rats underwent autopsies at the landing site. Readaptation studies were conducted in Moscow on the remaining flight rats for 25 days after the mission to assess their ability to readjust to Earth gravity. Autopsies were then performed on these rats and on rats in the ground control groups.

Results

The onboard centrifuge demonstrated that the organisms flown experienced stress due to prolonged weightlessness, and not to other flight factors.

Rodents

Flight rats had lowered body temperature, on average. Airflow, isolation, and confinement were thought to have contributed to this effect together with the altered muscular activity in microgravity. On recovery, rats appeared healthy and autopsies revealed no pathological disturbances attributable to space flight. Weight gain was lower in flight rats than in control animals. An increase in adrenal weight, reduced weight of thymus, spleen and some hind limb muscles, and a tendency toward reduced weight of lymph nodes were noted.

Flight rats showed an increased immune response, contradicting the hypothesis that space flight has a detrimental effect on cell mediated immunity. However, results also indicated an increased destruction of lymphoid cells. Survival of red blood cells was shown to be reduced in the flight animals, and hemolysis was significantly greater. In addition, some perturbations in endocrine function were also found.

Results of bone studies showed a decreased rate of bone formation rather than accelerated bone resorption in flight animals. A significant increase in bone formation was seen after the postflight recovery period.

Some abnormalities were noted in the eye tissue of flight rats. However, the tissue was normal for the most part, indicating that space flight of this duration would be safe for humans.

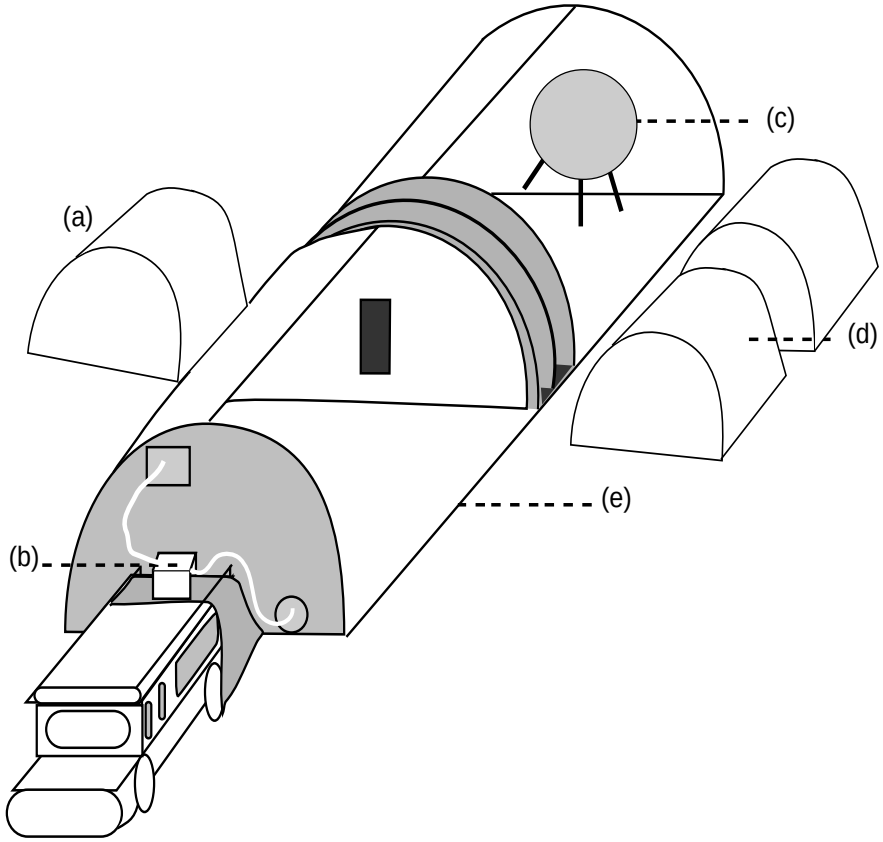


Figure 4-35: The field laboratory deployed at the recovery site: (a) lavatory; (b) diesel pump; (c) biosatellite; (d) generators; and (e) lab area.

During postflight readaptation studies, the flight rats displayed disturbances in vestibulo-motor function. These effects disappeared by the tenth postflight day.

Fruit flies

The only detrimental effect of space flight appeared to be a decrease in negative geotaxis and mating.

Fish

A high incidence of anomalous development was noted, but this effect was found to be due to the toxicity of new labeling tape on the plastic bags. The original labeling tape had been replaced with the new tape just prior to the flight. No major microgravity-related changes occurred in fish that developed in flight. Possible exceptions may be in those aspects of development that require gravity as a cue or a reference stimulus.

Plants

The development of viable embryos from carrot cells appeared to be unimpaired during space flight. A change in carbohydrate content was observed in carrot flown onboard; however, this effect was probably attributable to factors other than weightlessness. Tumors were found to be smaller in carrot disks exposed to weightlessness, a result that conflicts with ground-based studies using simulated microgravity. Differences were also noted in enzyme activity in carrot tissue exposed to weightlessness.

Radiation studies

The high-LET particle radiation in the biosatellite was measured.

Additional Reading

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MISSION PROFILE: Cosmos 936

Mission Duration: 19 days

Date: August 3–22 , 1977

Life Sciences Research Objectives (U.S.)

To study space flight effects on biological systems, and to differentiate between the effects of microgravity and radiation
To measure radiation levels in space
To evaluate centrifugation as a countermeasure to deleterious effects of space flight

Life Sciences Investigations (U.S.) [pp. 277-284]

Cardiovascular/Cardiopulmonary (C936-1)
Musculoskeletal (C936-2.1, 2.2, 3)
Radiation/Environmental Health (C936-4, 5)
Cell/Development Biology (C936-6)
Regulatory Physiology (C936-7)

Organisms Studied (U.S.)

Rattus norvegicus (rat)
Drosophila melanogaster (fruit fly)

Flight Hardware (U.S.) [pp. 524-527]

Radiation detectors
U.S.S.R. provided—see Appendix 3

Publications [pp. 425-427]

Cosmso 936

The U.S.S.R. launched the Cosmos 936 mission on August 3, 1977. Scientists from the U.S.S.R., the U.S., Czechoslovakia, France, Hungary, Poland, Romania, Bulgaria, and the German Democratic Republic conducted experiments in physics and biology on the mission. The biosatellite was recovered near Kustanay in Central Asia on August 22, after remaining in orbit for 19 days.

A notable feature of the mission was the use of two onboard centrifuges to rotate rat subjects throughout the flight. The artificial gravity environment provided by continuous centrifugation was expected to counteract space flight effects caused by microgravity. Effects caused by other space flight factors, such as the acceleration, noise, and vibration stresses of launch and re-entry, were not expected to change.

U.S. Life Sciences Research Objectives

The effects of space flight on various biological specimens were investigated during the mission, as during the previous Cosmos mission. An effort was made to differentiate between space flight associated effects on rat subjects that were caused by microgravity as opposed to those that were caused by other stresses. The effects of space flight were studied in bone and muscle, erythrocyte survival and lipid and carbohydrate metabolism. An experiment to examine the effect of space radiation on the retina was also carried out using rat subjects. Another study of space radiation was conducted without using biological material to determine various

physical parameters of the different components of radiation in space. Genetics and the aging process were studied in fruit flies.

U.S. Life Sciences Payload

Organisms

Thirty male, specific pathogen free rats (*Rattus norvegicus*) of the Wistar strain were flown onboard. At launch, they weighed 215 grams on average and were about 62 days old. Twenty of these rats experienced microgravity during the entire mission. The remaining 10 rats were subjected to continuous centrifugation throughout flight.

Fruit flies (*Drosophila melanogaster*) were used to study development and aging in the space environment. This species was also used to study genetic mutation rate.

Hardware

U.S.S.R.-Provided

Rats were housed in individual cages as on Cosmos 782. Four groups of cages, housing a total of 20 rats, were exposed to the weightless environment of the spacecraft. Two other groups of cages were placed on centrifuges (Fig. 4-36). The cages on the centrifuges differed from the other rat cages only in direction of air flow. In the centrifuged cages, air entered through holes in the cage doors rather than through the tops of the animal compartments. Air was forced through the cages when the centrifuges rotated. The centrifuges were activated at the time of spacecraft insertion into orbit and deactivated shortly before landing. Rotation on the centrifuges provided an acceleration of 1 g to the 10 rats housed in these cages.

Fruit flies were flown in standard cotton-stoppered vials placed within sheet metal containers.

U.S.-Provided

Hardware for the radiation dosimetry experiment consisted of several passive detectors. These included plastic nuclear track detectors, fission foil detectors, thermoluminescence dosimeters, and nuclear emulsions.

Operations

Three different types of control experiments were performed on the ground to help interpret flight data. All space flight conditions, except for microgravity and radiation, were simulated in a synchronous control experiment. Before this control experiment began, animals were subjected to launch stresses similar to those experienced by the flight specimens during launch, such as noise, vibration and acceleration. Re-entry stresses were similarly applied at the completion of the experiment. Specimen housing hardware was identical to the units used in flight. Animals placed on centrifuges within the spacecraft mock-up were rotated at the same rate as those in flight. However, because of terrestrial gravity, the resultant acceleration experienced by these animals was about 50 percent greater than the acceleration experienced by animals on the flight centrifuges.

A vivarium control experiment provided data on minimally stressed animals for comparison with the flight and control groups. Animals were housed in groups of five within standard cages (Fig. 4-37). Forty grams of the flight paste diet were provided to each animal every day during the preflight and orbit phases of the mission. During the readaptation period, 45 grams of food were provided per animal per day.

The third control was the Omega BIOS experiment, which was designed to provide data on a group of animals experiencing an acceleration closer to the animals on the flight centrifuges than those on the synchronous control centrifuges. This result was achieved by placing the animals on centrifuges with a smaller radius than the centrifuges used in flight or in the synchronous control experiment.

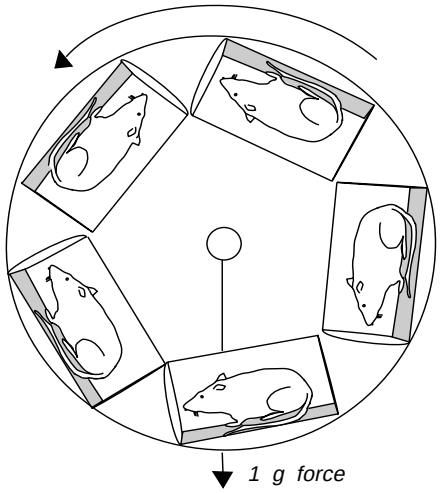


Figure 4-36: Some flight rats were exposed to artificial gravity on centrifuges.

Rats were housed in a vivarium during the period preceding launch. Flight and control rats experienced the same preflight treatment, including various injections and surgeries. Three weeks before launch, body temperature transmitters were implanted in the peritoneal cavities of 10 rats from the flight group and each of the control groups. The general health of the animals was monitored in daily examinations. Final selection of flight animals occurred a few days before launch.

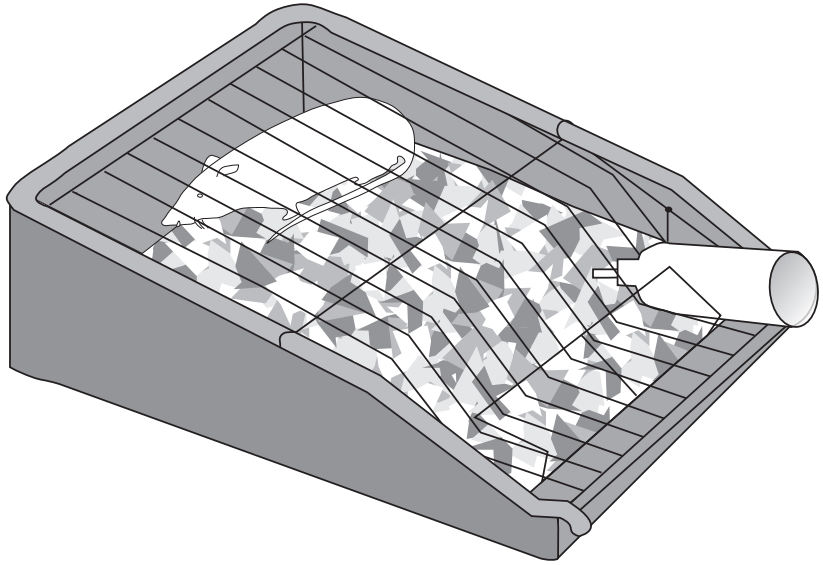
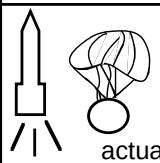
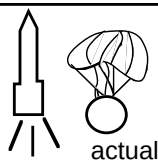
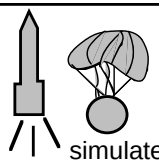
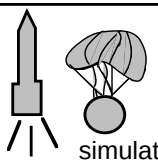
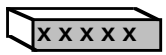
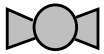
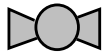


Figure 4-37: The cage used for the vivarium control experiment measured 450 x 310 x 160 mm.

During the flight, total gross body movement of the rats was monitored during two-hour periods every other day. It was observed that the total gross movement of the rats in a weightless condition was greater than that of rats on the flight centrifuges. The lowest body temperatures were recorded in the rats maintained in microgravity.

	Flight		Synchronous Control	Omega Bios Control	Vivarium Control
Number of rats	20	10	30	30	30
Launch/ recovery stress • noise • vibration • acceleration	 actual	 actual	 simulated	 simulated	none
*Food available**	40 grams/ animal/day	40 grams/ animal/day	40 grams/ animal/day	40 grams/ animal/day	200 grams/ 5 animals/day
Housing	 individual cages	 individual cages	 individual cages	 individual cages	 caged in groups of five
Environment • temperature • humidity • lighting, etc.	 spacecraft conditions	 spacecraft conditions	 simulated spacecraft conditions	 simulated spacecraft conditions	standard laboratory conditions
Gravitational force	microgravity	 centrifuge -1 g force	 flight-size centrifuge - 1.5 g force	 small-radius centrifuge - 1.04 g force	1 g force

**Amount consumed may actually be less.*
Table 4-6: Cosmos 936 flight and control rat experiments.

On day 16 of the synchronous control experiment, one of the centrifuges in the spacecraft mock-up malfunctioned; the 5 animals on it were removed.

Shortly after the spacecraft touched down, a portable field laboratory was assembled. Autopsies of flight animals began about three hours after spacecraft recovery. After these procedures were completed, biospecimens and the remaining live animals were transported to Moscow for further processing. Rats in the control groups underwent autopsies using the same experimental procedures as for flight animals. Bone, muscle, liver, and retinal tissue specimens from flight and control animals were then transported to the U.S. The radiation dosimetry materials were shipped in a special lead-lined case to shield them from exposure to any ground radiation sources. U.S.

Rodney Ballard

Prior to his joining NASA in the late 1960s, Rodney Ballard earned his Doctorate in Bacteriology from the University of California, Berkeley. Coincident with several positions within NASA, he was an Associate Professor of Microbiology at San Jose State University and President of San Benito Vineyards. Ballard was a significant contributor to furthering international cooperation for the SLSPO. He represented SLSPO at international joint working group meetings with France, Russia, Japan, Canada, Germany, and the ESA, and was a student of several languages. He chaired the U.S./French Rhesus Project Science Working Group and was a member of the U.S./U.S.S.R. Implementation Team on Space Biology.

Several years ago Ballard, a co-editor of this book, collected this story from Eugeny Ilyin (see page 123) during their flight from Moscow to San Francisco. Ballard found it so fascinating he immediately wrote it in his notebook, but then forgot it. While reviewing a draft of this book, about two months prior to his death, Ballard remembered the story and insisted on sifting through his notes, until he found it. The event described took place during the early days of U.S.S.R. biosatellite development.

In 1970, Oleg Gazenko, (see interview, page 148), then Director of the Institute of Biomedical Problems in Moscow, contacted Ilyin, Director of the Cosmos Biosatellite Program, with an urgent request. Evidently, Georges Pompidou, the president of France, was on a tour of the U.S.S.R. and Leonid Brezhnev, General Secretary of the Communist Party, invited him to attend a satellite launch. The available satellite had a lot of empty space in it and Ilyin was asked to quickly prepare some experiments for the space flight. He had only two hours to develop a mission scenario and eight days to deliver the experiments. Fruit flies, cell cultures, mice, and rats were selected.

The flight capsule had to be loaded 36 hours before launch and, unexpectedly, the Flight Director (not used to flying living systems) turned off the power and the ventilation fans could not operate. As an emergency measure, Ilyin conducted differential heating of the outside of the capsule hoping that enough convection could be produced to move air within the capsule until power was restored.

The mission lasted only three days, and both Brezhnev and Pompidou attended the launch. Unfortunately, not all of the rats survived the flight, but the other specimens did. This flight was, however, the first major step in developing the successful rodent life support systems that flew for 21 days on Cosmos 605 three years later.

Ballard found this story interesting because it illustrated some major differences in the overall environment in which space biology research was conducted in the U.S. and the U.S.S.R. One difference seemed to be the greater readiness of the U.S.S.R. to use space flight as a testbed to develop new life support systems and to accept failure as a possible first step to eventual success. Another difference was the relatively higher prestige historically attached to space research in the U.S.S.R., so that an unmanned biosatellite launch with some biological experiments on board would be deemed appropriate for the heads of France and the U.S.S.R. to attend.

scientists hand carried the flight and control fruit flies in their containers to individual laboratories.

Two weeks later, a second group of U.S. scientists visited the U.S.S.R. to attend the autopsies of the flight and control rats that were used for readaptation studies. Samples were once again returned to the U.S.

Results

Rodents

The rats were recovered in good condition. Experiment results indicated that several changes occurred during space flight. The finding that erythrocyte survival decreased in flight rats subjected to weightlessness supported observations made during previous missions. Bone stiffness and the rate of bone formation were found to decrease in space flight. The change in bone stiffness was corrected by centrifugation, but the rate of bone formation was not. The results of the muscle studies showed that hypogravity aggravates the atrophic effects of hypokinesis. Retinal tissue was detrimentally affected by space radiation. Changes noticed in liver tissue of flight rats exposed to weightlessness were not found in centrifuged flight rats, indicating that centrifugation during flight simulates some aspects of terrestrial gravity. Some of the muscle and bone anomalies seen in weightless flight rats were also not found in centrifuged flight rats.

Fruit flies

Although developmental processes in fruit flies seemed largely unaffected by space flight, the findings suggested that aging processes may be accelerated. Differences were also noted in the wings of flight flies as compared to ground controls.

Radiation studies

Important radiation dosimetric information useful in assessing the hazards to living systems in space was obtained.

Additional Reading

Rosenszweig, S.N. and K.A. Souza. *U.S. Experiments Flown on the Soviet Satellite Cosmos 936. Final Reports*. NASA TM-78526, September 1978.

Souza, K.A. The Joint U.S.-U.S.S.R. Biological Satellite Program. *Bioscience*, vol. 29, no. 3, 1979, pp. 160–166.

MISSION PROFILE: Cosmos 1129

Mission Duration: 18.5 days

Date: September 25–October 14, 1979

Life Sciences Research Objectives (U.S.)

To study the effects of space flight on biological systems
To study mammalian reproductive processes and avian embryogenesis in space
To measure radiation levels in space

Life Sciences Investigations (U.S.) [pp. 285-303]

Cell/Developmental Biology (C1129-1, 2)
Musculoskeletal (C1129-3.1, 3.2, 3.3, 3.4, 3.5, 4, 5, 6.1, 6.2, 7)
Plant Biology (C1129-8.1, 8.2, 9)
Radiation/Environmental Health (C1129-10)
Regulatory Physiology (C1129-11, 12, 13)

Organisms Studied (U.S.)

Rattus norvegicus (rat)
Coturnix coturnix (Japanese quail)
Daucus carota (carrot)

Flight Hardware (U.S.) [pp. 476-477, 552-553, 524-531]

Carrot Embryoid Containers
Carrot Tumor Growth Container II
Temperature Recording System
Radiation Detectors
U.S.S.R. provided—see Appendix 3

Publications [pp. 427-431]

Cosmos 1129

The Cosmos 1129 satellite was launched on September 25, 1979 and recovered in Central Asia on October 14, 1979. The spacecraft carried biological and radiation physics experiment packages from Czechoslovakia, France, Hungary, Poland, Romania, the German Democratic Republic, the U.S., and the U.S.S.R.

The U.S. investigations onboard included a radiation physics experiment and several biological experiments using rats, quail embryos, and plants.

U.S. Life Sciences Research Objectives

As it was for all Cosmos missions, the principal objective of Cosmos 1129 was to study the effects of space flight on biological systems, with a particular focus on the biomedical problems observed in men and animals during space flight. A concerted effort was made to maximize the science return from the mission. To this end, virtually every organ and tissue from the rat specimens flown was examined by investigators. Space flight effects on bone and muscle were examined in a series of studies on rats. Rats were also used in an attempt to study mammalian reproductive processes in space. A study of avian embryogenesis was carried out for the first time on this mission. Microgravity effects on plants were investigated using carrot tissue. The radiation exposure of the spacecraft and its contents was measured in a radiation dosimetry experiment.

U.S. Life Sciences Payload

Organisms

Thirty male specific pathogen free rats (*Rattus norvegicus)* of the Wistar strain were flown onboard and served as experimental subjects for a wide variety of physiological studies. When the experiments began, the rats were about 85 days old and weighed, on average, 300 grams. The flight rats were divided into five groups for experimental purposes. They were euthanized 7 to 11 hours after landing (group 1), 32 to 37 hours after landing (group 5), 6 days postflight (groups 2 and 3), or 29 days postflight (group 4).

Seven more Wistar rats were flown as part of the rat embryology experiment. Five of these were females weighing about 340 grams at launch and two were males weighing about 260 grams (Fig. 4-38).

Fertilized Japanese quail (*Coturnix coturnix*) eggs were flown to evaluate the effects of space flight on avian embryological development.

The effects of space flight on the rate of cellular metabolism were assessed by studying the growth of crown gall tumors in carrots (*Daucus carota*). Carrot cell cultures were used to determine if growth and development of plants were affected by space flight.

Hardware

U.S.S.R.-Provided

The 30 rats used in the physiology studies were kept in individual cages as on the Cosmos 782 and 936 flights.

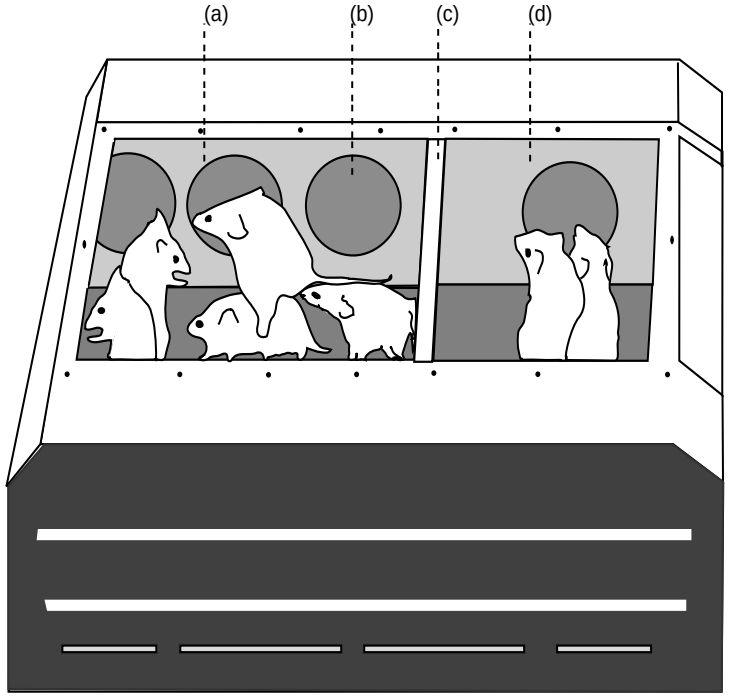


Figure 4-38: The rodent mating chamber: (a) female chamber; (b) feeding station;
(c) remotely activated partition door; and (d) male chamber.

The spacecraft also contained a rodent mating chamber for housing the seven rats used in the rodent embryology study (Fig. 4-38). At launch, the chamber was partitioned into two sections, which separated the two male rats from the five females. On the second day of flight, two doors in the partition were opened,

allowing the rats to mingle. There were eight feeding stations within the chamber. Ten-gram aliquots of the paste diet were presented at each station at six-hour intervals. Light was provided on a 12:12 light and dark cycle.

The quail egg incubator was an insulated chamber suspended from the mounting framework by heavy-duty elastic shock cords (Fig. 4-39). Within the chamber, the eggs were held between two perforated rubber strips located on the inner and outer steel rings. The chamber contained 5 egg rings, each bearing 12 eggs. When activated, the incubator could maintain a temperature of 37°C and a relative humidity of about 70 percent. The egg rings could be rotated within the incubator preflight and during the synchronous control experiment. In-flight rotation was not thought to be necessary. Egg rings were rotated continuously to simulate microgravity conditions during the synchronous control experiment.

U.S.-Provided

For the carrot tumor growth experiment, cross sections of carrot were inoculated with suspensions of the bacterium *Agrobacterium tumefaciens*. Each of the two flight canisters contained a stack of four dishes, with four inoculated carrot disks in each dish. A synchronous ground control experiment was conducted using similar canisters located in a spacecraft mock-up. Other ground control experiments were conducted using canisters oriented vertically or horizontally with respect to gravity, or rotated either vertically or horizontally on clinostats.

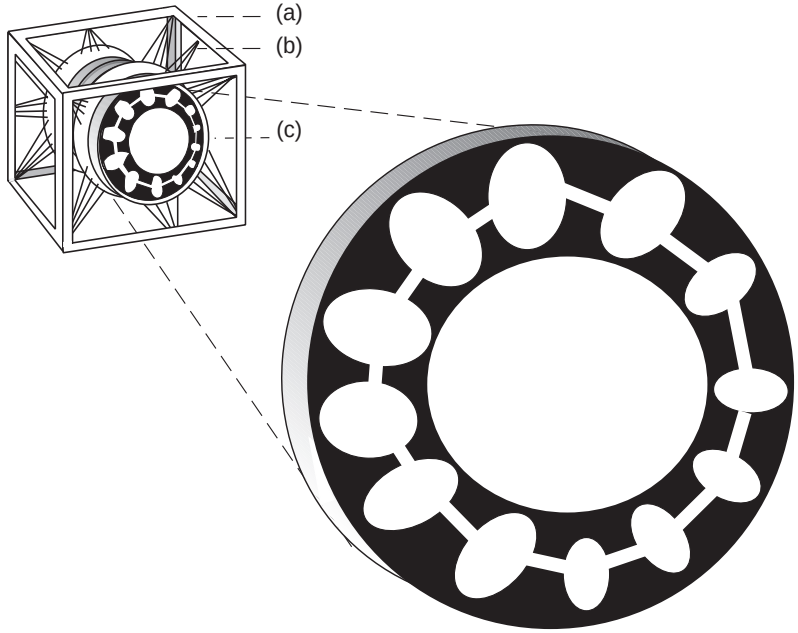
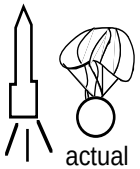
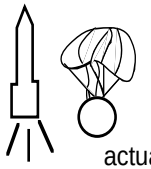
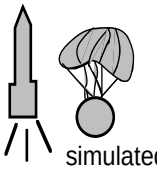
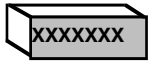


Figure 4-39: The quail egg incubator: (a) framework; (b) elastic shock cords; and (c) egg ring.

As on Cosmos 782, carrot cells and somatic embryos, respectively, were placed in agar culture medium in plastic petri dishes. The dishes were loaded into acrylic canisters and covered with aluminum end-caps. Two canisters were used in the flight experiment, and two in a synchronous ground control experiment that was conducted in simulated flight conditions. Two additional canisters were used in a stationary ground control experiment in which there was no flight simulation.

	Flight		Synchronous Control	Vivarium Control
Number of rats	30	7	30	30
Launch/recovery stress *• noise* *• vibration* *• acceleration*				none
*Food available**	40 grams/ animal/day	320 grams/ 7 animals/day	40 grams/ animal/day	200 grams/ 5 animals/day
Housing	 individual cages	 group of 7 in mating chambe	 individual cages	 caged in groups of five
Environment *• temperature* *• humidity* *• lighting, etc.*	 spacecraft conditions	 spacecraft conditions	 simulated spacecraft conditions	standard laboratory conditions
Gravitational force	microgravity	microgravity	1 g force	1 g force

**Amount actually consumed may be less.*
Table 4-7: Cosmos 1129 flight and control rat experiments.

Dosimetry packages were placed in two different locations. Stacks of plastic nuclear track detectors measured high-LET particles. Fission-foil detectors were used for neutron measurements. Thermoluminescent detectors measured total radiation doses from charged particles and gamma rays.

Operations

Two different types of ground control studies were performed to aid in interpreting flight studies. During the synchronous control study, the in-flight environment of the spacecraft was simulated as closely as possible. The study was initiated five days after launch and conducted in a spacecraft mock-up. Specimens were housed in mock-ups of flight hardware. At the start of the study, the specimens were subjected to launch stresses including noise, vibration, and acceleration. Re-entry stresses were applied after the study was completed. Food, water, lighting, temperature, humidity, and airflow closely approximated in-flight conditions.

The vivarium control study was conducted to provide data on minimally stressed rat specimens. Rats in groups 1, 2, 3, and 5 were housed in standard vivarium cages during the flight period. During the postflight period, they were kept in the same cages except on days 3, 8, and 13, when they were transferred to special metabolic cages for 36 hours at a time. Each animal received 40 grams of the flight paste diet once a day during the flight period, and 45 grams during the postflight period.

During the preflight period, candidate animal subjects were group housed in a vivarium. Flight and control groups of animals were similarly treated. The pellet/seed diet was switched to the flight paste diet two weeks before flight. General animal health was assessed in daily examinations.

Healthy animals for the flight and control groups were selected several days before launch.

Total gross body movement of the flight and synchronous control animals was monitored on odd-numbered days during the flight period (Fig. 4-40). Body temperatures of the group 4 animals in flight and synchronous control groups were obtained on even-numbered days. The light and dark cycle of group 4 rats was reversed on day 10 by subjecting the animals to 24 hours of continuous darkness. These rats were maintained at the reversed cycle after flight. The reversal was carried out as part of a study to determine space flight effects on the animals' circadian rhythms and on their ability to adapt to an altered day and night cycle.

On day two of flight, the partition separating male and female rats in the rodent mating chamber was opened and the rats were allowed to intermingle throughout the remainder of the flight.

The quail egg incubator was activated on the seventh day of the mission, allowing the temperature and humidity to be raised to 37°C and about 80 percent, respectively. These environmental conditions are appropriate for initiating embryo development in fertilized eggs. Unfortunately, the humidity control system failed on day 13 of the mission, causing the relative humidity to drop to cabin ambient level. This had detrimental effects on the developing quail embryos.

Within several hours of landing, a field laboratory had been set up at the Biosatellite recovery site. Autopsies were performed there on the group 1 rats. The remaining specimens were transported to Moscow. During the readaptation period that followed, the flight rats were subjected to a variety of tests. Following these operations, specimens were shipped to U.S. laboratories in specially designed containers. These containers could maintain the temperatures required to ensure specimen integrity.

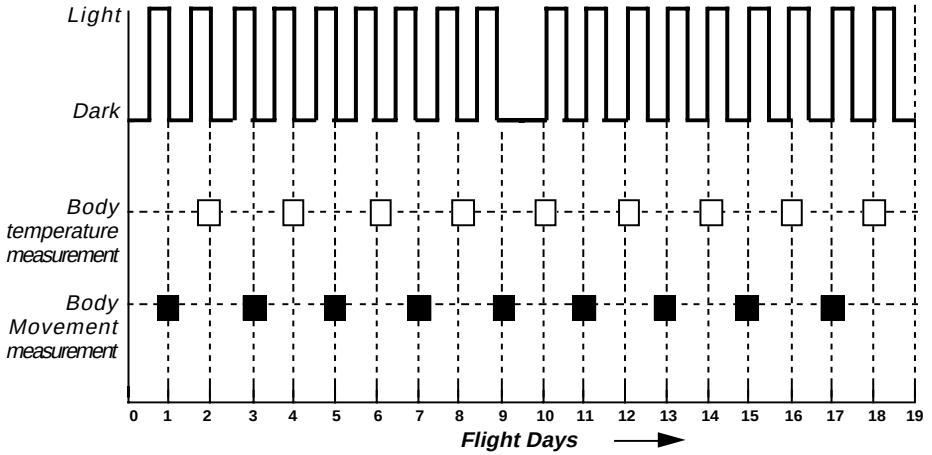


Figure 4-40: In-flight events for the rat experiments: body temperature and movement during flight were measured on alternate days. The light and dark cycle was reversed on day nine.

Results

Rodents

Flight rats were noted to be in good condition postflight. Postflight analyses indicated that changes had occurred in rat bone during space flight. Among these were decreased bone formation, decreased bone

volume, density and strength, increased fat content of bone marrow, and alterations in osteoblasts and osteoclasts.

Space flight effects on rat muscle included decreased muscle fiber size and a change in the proportion of fiber types. Metabolic effects and a change in body composition were also noted postflight.

Although all rats in the flight and synchronous control groups were subsequently shown to be fertile, none of them gave birth as a result of mating that may have occurred during the flight phase of the experiments.

Quail eggs

Only one of the quail embryos survived. In that embryo, development seemed normal. In the other embryos, decreased humidity appeared to have resulted in dehydration and increased fragility of the shell.

Plants

No changes were noted in the growth and development of plant cells and embryos in space. The tumor growth studies indicated that gravity compensation provided by ground -based clinostat rotation did not equal microgravity.

Radiation

The radiation dosimetry experiment provided a comprehensive picture of the radiation experienced by the spacecraft and its contents.

Additional Reading

Heinrich, M.R. and K.A. Souza. *U.S. Rat Experiments Flown on the Soviet Satellite Cosmos 1129. Final Reports.* NASA TM-81289, August 1981.

Heinrich, M.R. and K.A. Souza. *U.S. Plant and Radiation Dosimetry Experiments Flown on the Soviet Satellite Cosmos 1129. Final Reports.* NASA TM-81288, 1981.

Keefe, J.R. Experiment K-33: Rat and Quail Ontogenesis. *U.S. Experiments in the Soviet Satellite Cosmos 1129*. NASA TM-81289, August 1981, pp. 325–362.

MISSION PROFILE: Cosmos 1514

Mission Duration: 5 days

Date: December 14–19, 1983

Life Sciences Research Objectives (U.S.)

To study the effects of microgravity on circadian rhythms in rhesus monkeys
To study the effects of microgravity on morphological development of rat fetuses

Life Sciences Investigations (U.S.) [pp. 304-308]

Cardiovascular/Cardiopulmonary (C1514-1)
Cell/Developmental Biology (C1514-2, 3)
Regulatory Physiology (C1514-4, 5)

Organisms Studied (U.S.)

Rattus norvegicus (rat)
Macaca mulatta (rhesus monkey)

Flight Hardware (U.S.) [pp. 482-483, 472-473]

Circadian Rhythm Experiment Hardware
Cardiovascular Experiment Hardware
U.S.S.R.-provided—see Appendix 3

Publications [pp. 431-432]

Cosmos 1514

The first U.S.S.R. orbital flight of a nonhuman primate was accomplished on the Cosmos 1514 mission. Launch occurred on December 14, 1983. The biosatellite was recovered five days later.

On the mission, 2 monkeys flew as human surrogates, together with 10 pregnant rats. More than 60 experiments were performed by investigators from Bulgaria, Hungary, the German Democratic Republic, Poland, Romania, Czechoslovakia, France, the U.S.S.R., and the U.S. Three experiments on primates and another on the rat subjects were conducted by U.S. scientists.

The mission differed markedly from earlier Cosmos flights, both in terms of Soviet scientific goals and in the degree of cooperation required between the U.S. and the U.S.S.R. The two countries had to interact at a high level because much of the U.S. experiment hardware had to be integrated with the Soviet spacecraft and instrumentation systems.

U.S. Life Sciences Research Objectives

Experiments focused on the effect of weightlessness on various physiological parameters. A study of circadian rhythms was concerned with the synchronization of primate motor activity, body temperature, and skin temperature rhythms to a fixed light and dark cycle and to each other. Blood pressure and flow were monitored, to evaluate short- and long-term changes in these parameters. Changes in calcium metabolism were studied to determine the

effect of weightlessness on the skeleton. A neuro-ontogeny experiment was conducted to investigate space flight effects on the sensory development of rats that spent part of their prenatal gestation period in space.

U.S. Life Sciences Payload

Organisms

Two rhesus monkeys (*Macaca mulatta*) named Bion and Abrek were flown onboard. Both were about three years of age and each weighed approximately 4 kg. Height was a constraint in selecting animals for flight because there was limited vertical clearance in the animal capsules. The monkeys were conditioned to sit in the restraint couches and perform tasks for food rewards. Tasks included pressing a lever with their feet and tracking a moving light with their eyes. Monkeys were also trained to eat and drink from food and juice dispensers. All experimental subjects in the flight candidate pool were tested for their tolerance of launch and re-entry accelerations and of a several-hour stay in the right-lateral supine position, which would be experienced during prelaunch rocket maneuvers. Monkeys in the flight and control groups were implanted with sensors to measure several physiological parameters. Bion and several control monkeys also had implanted blood pressure and flow cuffs.

Ten pregnant female Wistar rats (*Rattus norvegicus*) were flown. Ground control groups contained the same number of rats. At the start of the flight or control experiments, the rats were at gestation day 13 of their 21-day cycle.

Hardware

U.S.S.R.-Provided

The spacecraft contained two monkey biological satellite (BIOS) capsules, which provided life support and experiment hardware (Fig. 4-32). The orientation of the two capsules within the spacecraft allowed the monkeys to view each other. The monkeys were placed within restraint couches in each capsule (Fig. 4-42). A remotely controlled chest restraint pad, a lap restraint plate with a leg divider, and upper and lower arm restraint straps were used to maintain each monkey in an appropriate, comfortable posture and to provide adequate support upon ground impact. The degree of thoracic restraint could be modified by ground command. Unidirectional airflow moved excreta toward a centrifugal collector underneath the restraint couch. The monkey could activate the paste diet and juice dispensers located in each capsule by operating bite switches. The monkey's access to these dispensers could also be controlled remotely from the ground. A video camera mounted within each capsule monitored in-flight animal behavior. A 16:8 light and dark cycle was provided in the monkey compartments during the flight.

A psychomotor system within each capsule was used to test the responses of the monkey subjects to various stimuli. The monkeys were trained to press a lever whenever a light signal was presented. The strength required to press the lever could be determined from the electromyogram (EMG) signals recorded from limb muscles. Vestibular tests conducted in flight included monitoring the eye-tracking response of the monkeys to a semicircular array of pro-

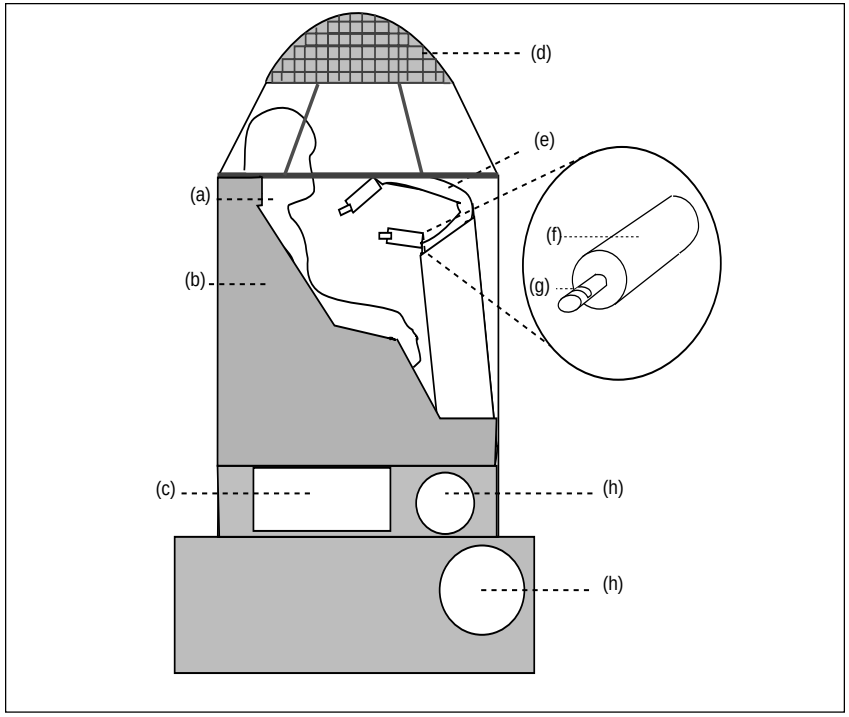


Figure 4-41: Cross section of the monkey BIOS, showing blowup of juice dispenser:(a) primate; (b) restraint couch; (c) waste; (d) air inlet screen; (e) display panel for vestibular tests; (f) juice and paste dispensers; (g) bite switch; and (h) paste and juice storage.

grammed lights located in front of each monkey. A sensor attached to the skull cap of the monkey registered that a correct response had been made when the sensor was pointed directly at the light on the panel. Juice rewards were presented for correct responses.

Rats were group housed in a single compartment called the rodent BIOS. The BIOS was formed by removing the partition that separated males and females in the Cosmos 1129 rodent mating chamber. It was equipped with ten nozzles for delivering paste food and 10 nozzles for dispensing water. Food was provided at regular intervals; water was available *ad lib* to the animals. Unidirectional airflow moved waste and debris into a waste collector located at the bottom of the cage. The light and dark cycle was regulated to 12:12.

Ground support equipment for the rat neuro-ontogeny experiment included maternity cages with video monitors, rotation and tilt devices for vestibular tests, and an olfactory, respiration, auditory, and visual testing system.

U.S.-Provided

All hardware required for conducting the cardiovascular experiment was developed by the U.S. Flight hardware included blood pressure and velocity transducers, signal conditioners, and control circuitry. The signal conditioners were powered by a lithium battery pack to minimize electrical noise. A cuff made of injection-molded plastic contained the pressure and flow transducers in its upper half. The lower part of the cuff consisted of several interchangeable shells that could fit around blood vessels of varying diameters. The cuff was surgically placed around the carotid artery of one of the flight monkeys and two control animals. Upon entry into orbit, the cardiovascular signal processor was activated by a signal from the biosatellite and data recorded on a Soviet tape recorder.

Test and calibration equipment to support flight hardware was also developed by the U.S. This equipment included custom-made

Oleg Gazenko

Oleg Gazenko was the former Director of the Institute of Biomedical Problems in Moscow. He still acts as an advisor to Anatoly Grigoriev, the current Director of the Institute.

Gazenko initiated the Cosmos biosatellite nonhuman primate program, which has been highly successful since its genesis in 1979. He recalls how difficult it was to decide to fly a primate for the first time. "It was obvious to us that we had to fly monkeys if we wanted to resolve the big questions about manned space flight. But our expertise was with other animals, like mice and dogs, so we didn't dare to fly monkeys for a long time." Close contacts with American primate researchers were valuable, Gazenko says. "They helped us to overcome the, well, let's say the mental barrier."

Gazenko has been involved in space life sciences research since the late 1950s. He sees great benefits from conducting biological experiments in space, particularly with animal models. Many opponents of animal flights believe that such flights are no longer justified because man is today able to live and work in space for fairly long periods of time. This argument is based on lack of understanding, Gazenko says. "It is true that we allow man to go into space because we know a lot about the potential hazards. But we don't know everything, and we can't guarantee 100 percent safety. Our confidence in allowing extended manned flights has to do with the proximity to the Earth. We have a good medical monitoring system onboard. It can send alarm signals to the ground if a crew member is in danger and if necessary, the flight can be terminated. Today, because missions are conducted in Earth orbit, it doesn't take too long to return men to Earth. On lunar or interplanetary flights, the situation will be drastically different. Then we will certainly understand the inadequacy of our knowledge. We have to continue our observations, not only on men, but also on animals, to make sure that we can cope with these different problems."

biological signal simulators (which were used for system integration purposes when no animals were present), oscilloscopes, signal generators, impedance meters, and receivers.

The U.S. developed custom solid-state recorders and a data readout and control unit to record skin and body temperature, ambient temperature, and motor activity for the circadian rhythm experiment during flight. A sensor and signal conditioner were used to measure activity, and a surface thermistor measured skin temperature. A Soviet-developed sensor was implanted subcutaneously for measuring body temperature.

Skeletal radiographs of the monkey during the preflight and postflight periods were obtained with a portable x-ray machine.

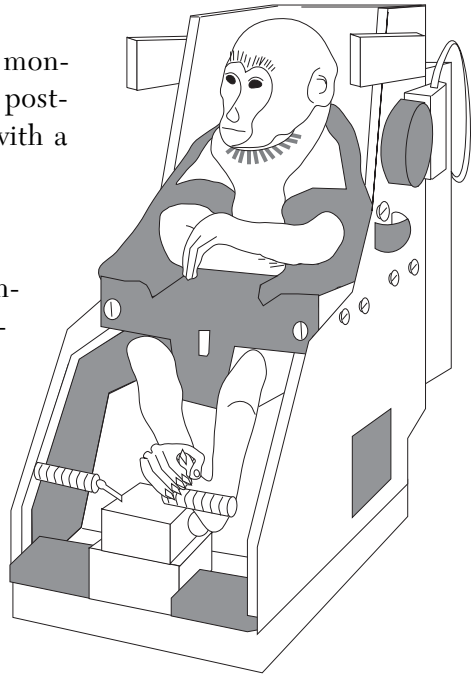


Figure 4-42: Animal restraint couch.

Operations

As in all Cosmos missions, control experiments were conducted on the ground to help interpret flight data. A synchronous control experiment was designed to simulate the flight experiment in all aspects except the condition of weightlessness. This was conducted several days postflight in the same spacecraft used for flight, with animals that were not flown on the mission. Postflight data was collected during a 21-day period following the completion of the synchronous control experiment. Data on animals housed in normal laboratory conditions were obtained in a vivarium control experiment. This experiment was meant to control all factors that were unique to the internal spacecraft environment such as lighting, humidity, and temperature. The protocol of the vivarium control for the monkey subjects varied according to the needs of the specific investigator.

Because many aspects of the U.S. experiments had to be carried out by Soviet specialists, adequate training was an important preflight activity. Soviet specialists implanted blood pressure and flow cuffs, assembled and installed experiment hardware within the BIOS capsules, and attached sensors to the monkeys. Their postflight role was equally significant; they were responsible for collecting, preparing, and coordinating transport of biosamples to the U.S. for analysis.

Training of flight and control monkey subjects began more than a year prior to launch. Physiological sensors were surgically implanted in the subjects during the three months preceding the start of the experiments. For the Soviet experiments, brain electrodes were implanted and skull caps attached to the subjects. These experiments also required implanting 15 subcutaneous electrodes in each monkey, including an ECG, EMG, rheoplethysmogram, and an axillary temperature transmitter. For the U.S. experiments, carotid pressure and flow cuffs were implanted in some monkeys.

Preflight control data were gathered from several flight candidate monkeys during a 10-day period about 2 weeks prior to launch. Flight and synchronous control subjects were selected after this period ended.

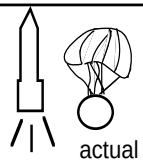
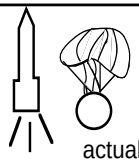
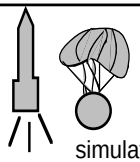
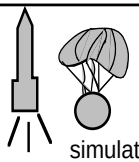
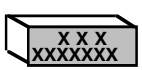
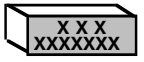
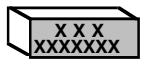
A remote signal from a U.S.S.R. controller activated the cardiovascular signal conditioners onboard the spacecraft shortly after it went into orbit. The signal conditioners were reactivated every two hours during the flight for five-minute periods of data acquisition.

A remote signal was also given after orbital insertion to loosen the chest restraint straps securing the animals to their couches, so that the monkeys could move more freely during the flight period. The straps were tightened before re-entry to provide maximum support for the animals during ground impact. During the five days spent in orbit, the monkeys followed the activities described in Figure 4-43. Video cameras located inside the capsules enabled ground personnel to monitor in-flight monkey behavior.

No special activities were conducted within the rat chamber during the flight.

Soon after the biosatellite was recovered, it was enclosed within a temperature-controlled portable field laboratory. Animals were removed, examined, and flown to Moscow.

Bion began to exhibit signs of ill-health on the second day after landing and died during postflight day three.

	Flight		Synchronous Control		Vivarium Control	
	Rats	*Monkeys*	*Rats*	*Monkeys*	*Rats*	*Monkeys*
Number of subjects	10	2	10	2	10	2
Launch/recovery stress *• noise* *• vibration* *• acceleration*	 actual	 actual	 simulated	 simulated	none	none
*Food available**	40 grams/ animal/day	500 grams/ animal/day**	40 grams/ animal/day	500 grams/ animal/day**	40 grams/ animal/day	unknown
Housing	 group housing	 individual capsules	 group housing	 individual capsules	 group housing	 colony cage
Environment *• temperature* *• humidity* *• lighting, etc.*	 spacecraft conditions	 spacecraft conditions	 simulated spacecraft conditions	 simulated spacecraft conditions	standard laboratory conditions	standard laboratory conditions
Gravitational force	microgravity	microgravity	1 g force	1 g force	1 g force	1 g force

**Amount actually consumed may be less.*
*** A total of 400 grams of juice per day per monkey also available if all psychomotor tasks completed.*
Table 4-8: Cosmos 1514 flight and control rat and monkey experiments.

Lyuba Serova described the launch of the Cosmos 1514 mission. "It was winter when we came with our animals to the launch site, and everything was covered with silver snow. I remember how beautiful it looked—the river, and the forest behind us. After we had placed our animals onboard, I looked up and the spacecraft seemed so tiny atop the rocket. At the same time, I thought about what a grand responsibility this experiment was. I felt very fortunate to be a part of the program. I think our predecessors would have been envious of the opportunities we've had."

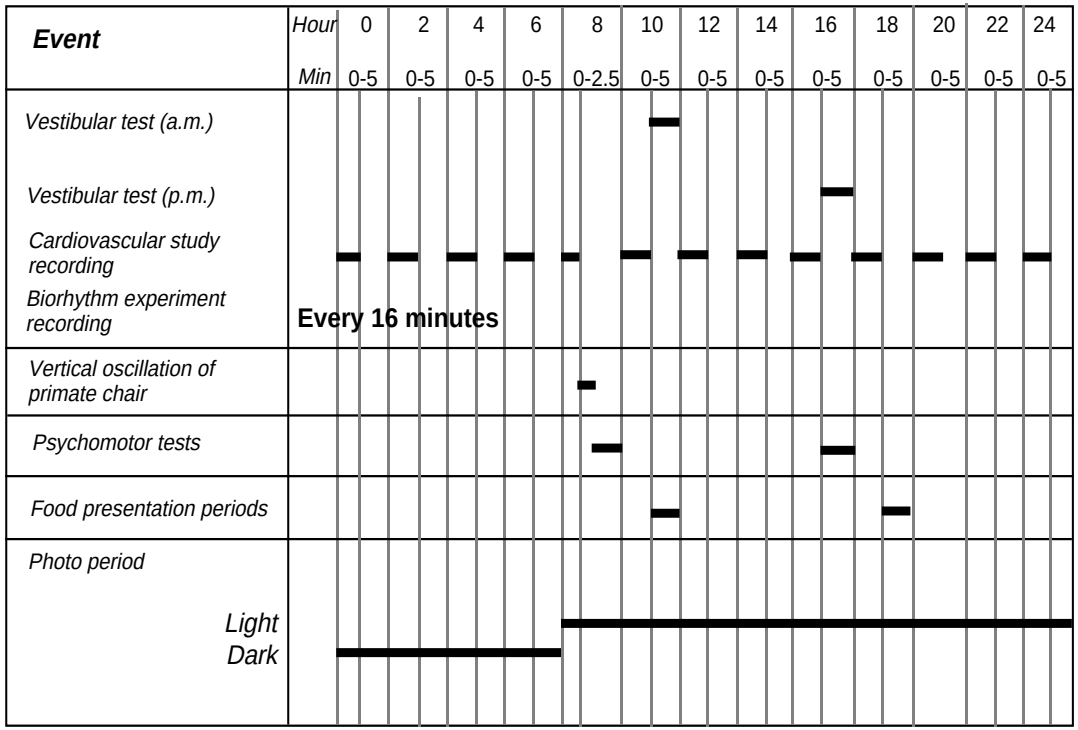


Figure 4-43: Daily schedule of in-flight events for the Cosmos 1514 primate

Postmortem analyses revealed that the cause of death was a strangulated bowel. The problem may have been congenital in nature and appeared to bear no relation to either the implanted instrumentation or the space flight. Postflight studies continued with the second monkey, Abrek. Because of the significant weight loss that occurred during the flight period, the Soviets decided to supplement the paste diet postflight with fresh food.

Cardiovascular data was transferred from the Soviet flight tape recorder to a U.S. ground-based recorder after the flight. Circadian rhythm data was also transferred from solid-state memory to permanent copy at this time.

Five of the rats were euthanized at the recovery site and biospecimens were stored for transport to Moscow. The remaining five females were flown to Moscow, where they delivered their litters approximately five days after landing. Four of the females gave birth to at least 12 pups, while the fifth delivered stillborn pups after undergoing a prolonged labor. Pups and mothers were transferred to special cages for behavior studies.

Results

Primates

Patterns of food and juice consumption indicated that Abrek adapted to the flight conditions faster than Bion. Bion was less active and began to drink juice only on the third day of flight and to consume food on the fourth. Both monkeys lost weight during the flight. Body dehydration was noted at recovery. Circulating blood and plasma volume and extracellular and interstitial fulid had decreased, while venous hematocrit had increased.

Noticeable changes were evident in Bion's cardiovascular system early in the flight. Signs of adaptation were noted from the third to the fifth day of flight.

Circadian rhythms of activity and temperature were shown to persist in the space environment although entrainment to the light and dark cycle appeared to be weaker than on Earth. Changes were also seen in the levels of circulating calcium.

Rodents

Pregnant females gained less weight during flight than during the synchronous control experiment. Decreases in muscle and liver mass, hemoglobin, and amniotic fluid were also apparent in flight rats.

Offspring of flight dams appeared to have impaired auditory detection capability and possibly vestibular supersensitivity. Other perturbations in development caused by the space environment may have been compensated during the five days between biosatellite recovery and birth.

Additional Reading

Gazenko, O.G., ed. *Ontogenesis of Mammals in Microgravity*. NASA TM- 103978, April 1993. [A translation of Ontogenez Mlekopitayuschikh vNevesomosti, Nauka Publishers, Moscow, 1988.]

Mains, R.C. and E.W. Gomersall. *U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514. Final Reports.* NASA TM-88223, May 1986.

MISSION PROFILE: Cosmos 1667

Mission Duration: 7 days

Date: July 10–17, 1985

Life Sciences Research Objectives (U.S.)

To study blood pressure and flow responses in primates exposed to microgravity
To correlate other simultaneously recorded physiological information with cardiovascular results

Life Sciences Investigations (U.S.) [p. 309]

Cardiovascular/Cardiopulmonary (C1667-1)

Organisms Studied (U.S)

Macaca mulatta (rhesus monkey)

Flight Hardware (U.S.) [pp. 474-475]

Cardiovascular Experiment Hardware - Mod. 1
U.S.S.R.-provided—see Appendix 3

Publications [pp. 432-433]

Cosmos 1667

The second Cosmos biosatellite mission with a primate payload was launched on July 10, 1985. The biosatellite was recovered on July 17 after the 7-day mission was completed. Mission parameters were very similar to those of Cosmos 1514. Countries participating in the mission included the U.S.S.R., the U.S., France, Czechoslovakia, the German Democratic Republic, Poland, Romania, Bulgaria, and Hungary. The U.S. conducted a single cardiovascular experiment on one of the two flight monkeys. Rats and other organisms were also flown, but no U.S. experiments were conducted on those specimens.

Although the U.S. experiment on the Cosmos 1667 mission was meant to be a repeat of the Cosmos 1514 cardiovascular experiment, several improvements were implemented on this mission. Modified post-surgery animal handling procedures minimized the risk of damaging the transducer implants. Data was sampled and recorded more frequently during the in-flight period. Two monkeys with flight-type cardiovascular instrumentation were studied in a ground-based synchronous control experiment; postflight cardiovascular tests were not conducted after Cosmos 1514. Postural tilt tests were conducted during the preflight and postflight periods in several animals to establish a ground-based pool of normal data for this procedure. This data was compared with the similar body fluid shifts thought to occur in flight. Instrument calibration procedures were modified on this mission to ensure that blood pressure measurements would be accurate.

U.S. Life Sciences Research Objectives

The main objective of U.S. participation in the Cosmos 1667 mission was to measure carotid artery pressure and blood flow during the in-flight period. The U.S. provided all flight and ground support instrumentation for this experiment. Raw analog data from flight and ground control experiments were transferred to the Cardiovascular Research Laboratory at ARC for analysis. Hemodynamic data were to be correlated with concurrently recorded Soviet data. A similar correlative study was performed during the Cosmos 1514 mission, where blood flow velocity was compared to cardiac output as determined by impedance cardiography. Another goal of the primate cardiovascular experiment on Cosmos 1667 was to use the data obtained to estimate oxygen delivery capacity to the brain during space flight. This procedure was postponed to a future mission because the external carotid artery needed to be ligated to measure brain blood flow.

U.S. Life Sciences Payload

Organisms

Two rhesus monkeys (*Macaca mulatta*) named Gordyy and Oomka were flown onboard the biosatellite. Each animal weighed approximately 4 kg. Both were instrumented for Soviet neurophysiology studies. The instruments consisted of bilaterally implanted microelectrodes in the vestibular nuclei, and electrooculogram and electroencephalogram electrodes. The U.S. cardiovascular experiment was conducted on Gordyy, who was implanted with a device to measure blood pressure and flow in the left common carotid artery.

Hardware

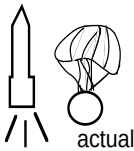
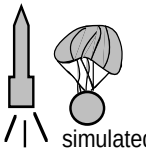
As in the Cosmos 1514 mission, monkeys were housed in Soviet BIOS capsules. U.S. hardware developed for the Cosmos 1514 cardiovascular experiment was used again on this mission. A barometric pressure recorder mounted in the primate capsule was used to correct and normalize the implanted pressure sensor to 760 mm of mercury.

Operations

Two monkeys with cardiovascular instrumentation, Kvak and Samurai, were used in a synchronous control experiment. A vivarium control experiment was also carried out to determine the animals' responses in a non-stressed environment. Orthostatic (tilt) tests were performed on Gordyy, Kvak, Samurai, and three other animals with cardiovascular instrumentation. These tests were designed to simulate the fluid shifts that occur in animals exposed to microgravity.

Flight candidate monkeys were trained to operate flight food and juice delivery systems and to tolerate simulated launch and reentry g loads, flight couch confinement, isolation, and other environmental factors. Other training consisted of behavioral tasks related to Soviet vestibular studies.

Cardiovascular instrumentation was implanted in one flight animal and in two control animals about two months prior to the flight. Tilt tests were performed on these animals during the preflight period. Preflight data were also gathered on transducer cross calibration, control monitoring, and bioengineering tests.

	Flight	Synchronous Control	Vivarium Control	Tilt Tests
Number/names of CV-instrumented monkeys	1 (Gordyy)	2 (Kvak, Samurai, Gordyy)	3 (Angel, Fronya, Troll)	6 (Gordyy, Kvak, Samurai, Angel, Fronya, Troll)
Launch/recovery stress • noise • vibration • acceleration	 actual	 simulated	none	not applicable
*Food available**	500 grams/ animal/day**	500 grams/ animal/day**	unknown	not applicable
Housing	 individual capsules	 individual capsules	 colony cage	not applicable
Environment • temperature • humidity • lighting, etc.	 spacecraft conditions	 simulated spacecraft conditions	standard laboratory conditions	not applicable
Gravitational force	microgravity	1 g	1 g	postural tilt

**Amount actually consumed may be less.*
***A total of 400 grams of juice/day/monkey also available if all psychomotor tasks completed.*
Table 4-9: Cosmos 1667 flight and control monkey experiments.

During the flight, 5-minute sampling periods every 2 hours in the 16-hour "lights on" period provided carotid flow, carotid pressure, ECG, time code, and ambient pressure data (Fig. 4-44). Data were sampled for 5 minutes every 30 minutes during the "lights off" period.

Tilt tests were performed on the flight animal with cardiovascular instrumentation (Gordyy) and one instrumented control animal

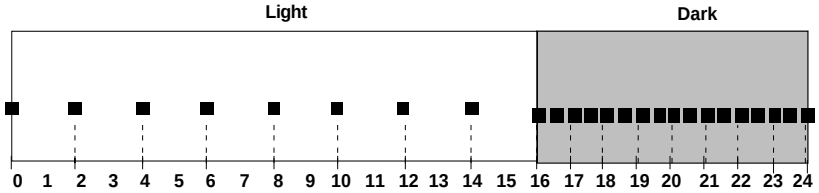


Figure 4-44: Daily in-flight data sampling on Cosmos 1667. Each sampling period

(Samurai) three days after flight. Both of these animals and one other control animal (Kvak) participated in a ground-based synchronous control experiment one month after the termination of the flight experiment. Tilt tests were again performed, this time on Gordyy, Samurai, Kvak, and three others, after the synchronous control experiment was completed. After all necessary tests had been performed, the data were transferred from Soviet tape recorders to U.S. tape recorders.

Results

The experiment performed on this mission served to strengthen the data obtained from the experiment conducted aboard Cosmos 1514. The most apparent cardiovascular changes were a rapid initial decrease in heart rate followed by further decreases upon continued exposure to the microgravity environment. The changes appeared to be adaptive, and may have served to maintain an adequate supply of blood to the brain during space flight.

Additional Reading

Hines, J.W. and M.G. Skidmore. *U.S. Primate Cardiovascular Experiment Flown on the Soviet Biosatellite Cosmos 1667. Final Report.* NASA TM-108803, May 1994.

MISSION PROFILE: Cosmos 1887

Mission Duration: 12.5 days

Date: September 29–October 12, 1987

Life Sciences Research Objectives (U.S.)

To quantitatively analyze the skeletal changes in primates exposed to microgravity
To study effects of space flight on biological systems in rats
To measure radiation levels in space

Life Sciences Investigations (U.S.) [pp. 310-342]

Cardiovascular/ Cardiopulmonary (C1887-1.1, 1.2)
Immunology/ Microbiology (C1887-2)
Musculoskeletal (C1887-3, 4, 5.1, 5.2, 5.3, 5.4, 6, 7, 8, 9, 10.1, 10.2, 11, 12, 13)
Neuroscience (C1887-14, 23.2)Radiation/ Environmental Health (C1887-15)
Regulatory Physiology (C1887-16, 17.1, 17.2, 18, 19, 20, 21 , 22, 23.1, 24.1, 24.2, 24.3)

Organisms Studied (U.S.)

Rattus norvegicus (rat)
Macaca mulatta (rhesus monkey)

Flight Hardware (U.S.) [pp. 524-525, 532-533]

Radiation Detectors
U.S.S.R.-provided—see Appendix 3

Publications [pp. 433-440]

Cosmos 1887

On September 29, 1987, the U.S.S.R. launched Cosmos 1887, a biosatellite carrying biological and radiation physics experiments from 9 countries. The biosatellite returned to Earth on October 12 after a mission of 12.5 days. The landing was several hundred miles from the expected recovery site, which caused considerable difficulties.

The biological payload on the spacecraft included 2 primates, 10 rats, fruit flies, stick insects, beetles, guppies, *Hynobiidae, chlorella* ciliates, newts, and corn. More than 50 NASA-sponsored scientists were involved in conducting the 33 U.S. experiments onboard. One of these experiments, a study of radiation levels in the space environment, did not require the use of any biological subjects. The U.S. conducted only one experiment on the primates flown on the biosatellite. The remaining U.S. experiments were performed on tissue samples from five of the flight rats. A number of these experiments were extensions of the studies conducted on the Spacelab 3 mission in April 1985.

The other countries involved in conducting experiments on the mission were the Soviet Union, Poland, Czechoslovakia, the German Democratic Republic, France, Romania, Bulgaria, and Hungary. The ESA also sponsored some experiments.

The U.S. was responsible for developing flight and ground-based hardware, testing of hardware and experiment procedures, developing rat tissue sampling procedures, and transferring tissues and data from the Soviet Union after the flight. One of the

mission's noteworthy features was the Rat Biospecimen Sharing Program, which allowed scientists in diverse disciplines to analyze a large number of rat tissue samples.

U.S. Life Sciences Research Objectives

The objective of the U.S. experiments was to investigate the effect of microgravity on various body systems. The primate experiment was designed to study the growth and development of the peripheral skeleton. Rat studies encompassed a broad array of scientific disciplines. The effects of microgravity on cardiac, liver, small intestine, and bone tissue, liver function, skeletal growth, hormone levels, and metabolism were studied using various approaches. Other studies investigated changes in the immune, nervous, and reproductive systems, in muscle and connective tissue, and in skeletal and mineral homeostasis. Another experiment was conducted to evaluate radiation exposure during the flight and to measure the shielding effectiveness of the spacecraft.

U.S. Life Sciences Payload

Organisms

Ten 12-week-old male specific pathogen free Wistar rats (*Rattus norvegicus*) were flown on the biosatellite. Two rhesus macaques (*Macaca mulatta*), named Drema and Yerosha, also occupied the biosatellite.

Hardware

U.S.S.R.-Provided

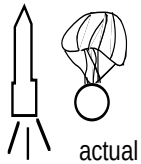
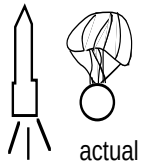
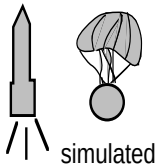
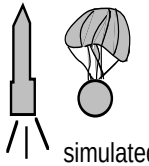
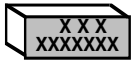
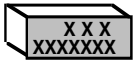
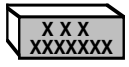
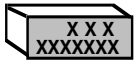
The rats were housed together in a single rodent BIOS as in Cosmos 1514. An atmospheric pressure of 760 mm mercury was maintained inside the cage. Average humidity within the BIOS was about 58 percent, and the ambient temperature ranged from 22° to 23°C. Lights remained on for 16 out of every 24 hours.

The monkey BIOS capsules used to house the flight monkeys were identical to the ones used on the Cosmos 1667 mission.

U.S.-Provided

Hardware for the radiation dosimetry experiment included a Lexan box detector assembly, a thermoluminescence detector assembly, sealed plastic stacks, and activation foil assemblies placed inside and outside the spacecraft.

Four types of temperature controlled biotransporters were developed for the mission. These units were essential for ensuring the success of the Rat Biospecimen Sharing Program. The electrically powered biotransporter used to move specimens from the recovery site to Moscow could be kept at 23°C for at least 40 hours. If needed, it could also be set to 6°C or 37°C. Specimens were transferred from Moscow to the U.S. in 4°C, –23°C or –70°C biotransporters, depending on the requirements of specific tissues. The 4°C transporter had a battery-

	Flight		Synchronous Control		Vivarium Control		Basal Control (preflight)
	Rats	*Monkeys*	*Rats*	*Monkeys*	*Rats*	*Monkeys*	*Rats*
Number of subjects	10	2	10	2	10	2	10
Launch/recovery stress *• noise* *• vibration* *• acceleration*					none	none	none
*Food available**	40 grams/ animal/day	500 grams/day**	40 grams/ animal/day	500 grams/day**	40 grams/ animal/day	unknown	40 grams/ animal/day
Housing	 group housing	 individual capsules	 group housing	 individual capsules	 group housing	 colony cage	 group housing
Environment *• temperature* *• humidity* *• lighting, etc.*	 spacecraft conditions	 spacecraft conditions	 simulated spacecraft conditions	 simulated spacecraft conditions	standard laboratory conditions	standard laboratory conditions	standard laboratory conditions
Gravitational force	microgravity	microgravity	1 g force	1 g force	1 g force	1 g force	1 g force

**Amount actually consumed may be less.*
*** A total of 400 grams of juice/day/monkey also available if all psychomotor tasks completed.*
Table 4-10: Cosmos 1887 flight and control rat and monkey experiments.

operated heating system and refrigerant packs, and was capable of maintaining temperatures between 2°C and 10°C for at least 72 hours. The –23°C biotransporter also had refrigerant packs and could keep specimens frozen at temperatures between –5°C and –35°C. The –70°C biotransporter contained dry ice and could keep specimens frozen for at least 48 hours.

Operations

The general experiment design for this mission was similar to that on earlier missions. Basal, synchronous and vivarium control experiments were conducted, on 3 groups of 10 rats. Preflight control data were obtained from the basal control group. Diet, temperature, humidity and lighting were similar to conditions expected in flight. The vivarium control group was maintained in standard laboratory conditions. The same amount of food was available to animals in this group as for the flight group, but it was provided in a single daily ration. The environmental conditions experienced by the flight animals during the period immediately following landing were not simulated for this group. Animals in the synchronous control group were exposed to conditions identical to those experienced by the flight animals, except for the re-entry g force and the postflight transportation conditions. These conditions included the g force and vibration of launch, the 42-hour postflight food deprivation, and the disrupted lighting regimen and temperature variations experienced by the flight animals because of the unexpected off-target landing. Euthanasia of synchronous control rats was postponed for the same period as for the flight experiment.

X-rays were taken of both legs and both arms of flight monkeys at two months and one month before flight, for a musculoskeletal study.

Rats were acclimated to flight-type cages beginning nearly three weeks before launch. Rats in the basal control group were euthanized five days prior to launch. Tissue samples from these rats were frozen or refrigerated for later shipment to the U.S. Flight rats were placed in the spacecraft 46 hours before launch.

No preflight measurements were taken for the radiation dosimetry experiment because all dosimeter units were designed for a single exposure. Dosimeters were assembled in the investigator's laboratory with NASA oversight, and were then transported to the U.S.S.R. in a specially designed lead-lined case. Before launch, the dosimeters were placed in various external and internal locations on the spacecraft and the craft photographed to document the arrangement of the units.

During the flight, rats consumed about 50 grams of the paste diet daily, which included approximately 35 ml of water. The rats also drank about 2.5 ml of water per day.

One of the monkey feeders began to malfunction during the second day of flight. Extra juice was made available to the monkey by a backup juice dispenser. The health condition of the animal was carefully monitored from the ground. A decision was eventually made to shorten the mission to 12.5 days from the planned length of 14 days. The normal light cycle was interrupted before re-entry into the Earth's atmosphere so that the animals would be awake for landing.

The dosimeters located outside the spacecraft were held in a flat container with a closeable lid. This lid was opened after launch and remained open throughout the time in orbit. Before re-entry into the Earth's atmosphere the lid was closed to protect the dosimeters.

The biosatellite landed in Siberia about 1800 miles from the expected recovery site. Landing force was estimated to be about 3–4 g. The spacecraft was eventually located about three hours after it landed. A heated tent was constructed around the spacecraft to keep the animals warm since the outside temperature ranged from –5°C to –20°C. The lights had become extinguished during the landing, so the animals remained in the dark until they were moved from the biosatellite into transport cages. Because the ventilation system functioned well after landing, an adequate air supply was maintained within the biosatellite.

Although the biosatellite was recovered 3 hours after landing, 20 more hours elapsed before the animals were transferred to transport cages. The cages reached the planned recovery site only after being transported in a bus, an airplane, and a van for 10 more hours.

Monkeys were subjected to brief clinical examinations at the recovery site. Other examinations were carried out from 2 to 12 days after recovery. A 25 percent weight loss was noted in Yerosha, the monkey with the inoperable in-flight feeder. The other monkey, Drema, gained 140 grams. Postflight x-rays were taken of both monkeys and the six control monkeys after the flight.

Temperature was not recorded in the rat cages after the biosatellite landed, but postflight calculations indicated that the internal temperature had decreased slowly to a minimum of about 12°C. The rats were apparently not adversely affected by the low temperature, since they neither huddled nor were cold to the touch when the cages were opened. They seemed healthy and well groomed. Because the rat feeders did not function after landing, the rats were deprived of food for 42 hours from the time they were last fed in flight. It is not known whether the rats had access to water during the period of time between landing and recovery. Both food and water were provided to the animals after they were moved from the flight cages to the transport cages. The flight rats were euthanized 48–56 hours after landing, and tissue samples were obtained by a team of Soviet specialists. Some 2000 tissue samples were shipped to the U.S. in the temperature-controlled biotransporters.

The dosimetry packages were returned to the U.S. in a lead-lined transfer box 10 days after the biosatellite was recovered. From the spacecraft's re-entry profile, it was determined that some high temperatures (not greater than 88°C) had existed in the vicinity of the external dosimeters. However, the period of exposure to these temperatures appeared to have been too brief to produce significant differences in detector response.

Results

Primates

It was concluded that a modification of techniques used in the primate skeleton experiment would enable subtle skeletal changes to be found. Significant skeletal changes were noted in the flight monkey with the malfunctioning feeder. Some changes were also seen in the other flight monkey.

Rodent

The rat studies yielded good results on changes in muscle, bone, heart, and liver tissue, liver function, testes, and metabolic

and endocrine functions that presumably occurred as a consequence of space flight.

Additional Reading

Ballard, R.W. and J.P. Connolly. U.S./U.S.S.R. Joint Research in Space Biology and Medicine on Cosmos Biosatellites. *FASEB Journal*, vol. 4, no. 1, January 1990, pp. 5–9.

Connolly, J.P., R.E. Grindeland, and R.W. Ballard, eds. *U.S. Experiments Flown on the Soviet Biosatellite Cosmos 1887. Final Reports*. NASA TM-102254, February 1990.

Grindeland, R. Cosmos 1887: Science Overview. *FASEB Journal,* vol. 4, no. 1, January 1990, pp. 10–15.

MISSION PROFILE: Cosmos 2044

Mission Duration: 14 days

Date: September 15–29, 1989

Life Sciences Research Objectives (U.S.)

To repeat the rat analyses on Cosmos 1887
To study the effect of space flight on circadian rhythms, temperature regulation and metabolism in the rhesus monkey
To study neuromuscular adaptation and the neurovestibular effects of space flight in the rhesus monkey
To measure radiation levels in space

Life Sciences Investigations (U.S.) [pp. 343-390]

Cardiovascular/Cardiopulmonary (C2044-1, 2.1, 2.2, 2.3, 2.4, 3)
Immunology/Microbiology (C2044-4.1, 4.2)
Musculoskeletal (C2044-5, 6, 7, 8, 9.1, 9.2, 9.3, 9.4, 10, 11.1, 11.2, 12.1, 13.1, 13.2, 13.3, 14.1, 15.1, 15.2, 16.1, 16.2, 17)
Neuroscience (C2044-12.2, 14.2, 18, 19)
Radiation/Environmental Health (C2044-20)
Regulatory Physiology (C2044-21.1, 21.2, 22, 23, 24, 25, 26.1, 26.2, 27.1, 27.2, 27.3, 28, 29.1, 29.2)

Organisms Studied (U.S.)

Macaca mulatta (rhesus monkey)
Rattus norvegicus (rat)

Flight Hardware (U.S.) [pp. 484-485, 554-555, 534-535]

Circadian Rhythm/Temperature Experiment Hardware–Mod. 1
Temperature Recording System–Mod. 1
Radiation Detectors
U.S.S.R.-provided—see Appendix 3

Publications [pp. 440-451]

Cosmos 2044

Cosmos 2044 was the seventh Soviet biosatellite to orbit the Earth with joint U.S./U.S.S.R. experiments onboard. The mission was launched from Plesetsk on September 15, 1989. The spacecraft was recovered on September 29 after flying for 14 days. Hungary, the German Democratic Republic, Canada, Poland, Great Britain, France, Romania, Czechoslovakia, and the ESA also participated in the mission.

The joint U.S./U.S.S.R. experiments were conducted on 2 rhesus monkeys and 10 rats that were flown onboard the Cosmos 2044 biosatellite. The biological payload also included fish, amphibians, insects, worms, protozoans, cell cultures, and plants. Many of the studies conducted on the biosatellite were repeats of experiments flown previously on Cosmos 1887. The results from many of those experiments were inconclusive because of the delay in recovering the biosatellite. Consequently, the experimental subjects had partially readapted to Earth gravity before postflight testing could be performed.

U.S. Life Sciences Research Objectives

The Rat Biospecimen Sharing Program included 43 experiments conducted by U.S. scientists on tissues from the flight rats. The goal of the program was to extend the investigations conducted aboard the Cosmos 1887 biosatellite, with a shorter specimen recovery period. Methodologies used in Cosmos 1887 experiments were duplicated and extended to maximize comparability. Among these

were studies of the effects of microgravity on various tissues such as the heart, lungs, small intestine, liver, muscle, bone, connective tissue, and testes. Experiments were also carried out to determine the response of the immune and endocrine systems to space flight. Other studies were concerned with processes such as tissue repair and skeletal growth in the space environment. The primates flown on the spacecraft acted as experimental subjects for five studies that dealt with the effects of space flight on neurovestibular, behavioral, muscular, circadian rhythm, metabolic, and thermoregulatory responses. Another experiment was performed, without using biological subjects, to evaluate the radiation environment inside and outside the spacecraft.

U.S. Life Sciences Payload

Organisms

Primate experiments were conducted in flight on two male Rhesus monkeys (*Macaca mulatta*) named Zhakonya and Zabiyaka. These and other control monkeys were implanted with several electrodes and sensors for recording physiological parameters.

Subjects for the rat experiments were male specific pathogen free Wistar rats. The flight group and each of 3 control groups contained 10 rats. Five of the rats in each group were surgically treated so that tissue repair in space could be studied. Apart from the synchronous control and the vivarium control experiments, another control was carried out on this mission. The rats in this third control group were placed in individual cages and suspended by their tails in a head-down position, so that the weight of the lower body was supported by the forelimbs. The objective was to remove static loads from the hindlimbs and thereby to simulate the physiological changes that occur in microgravity. Preflight data were obtained from a basal control group of 10 untreated rats. Diet, temperature, humidity and lighting for this group were kept consistent with conditions expected in flight. Rats in this group were euthanized at the time of launch in order to obtain baseline tissue samples.

Hardware

The monkey subjects were housed in flight in two primate BIOS units, similar to the ones used in previous Cosmos missions (see the Cosmos 1514 section). The food/juice dispenser nozzle was modified to prevent the malfunction that occurred on Cosmos 1887. A great deal of hardware was used in conducting the preflight, in-flight, and postflight primate experiments. The U.S.S.R. provided much of this hardware. The U.S. developed flight hardware for the circadian rhythm/thermoregulation experiment, two ambient temperature recorders for the radiation dosimetry experiment, various ground support hardware for the other experiments, and temperature-controlled biotransporters for transferring specimens from the U.S.S.R. to the U.S.

Several sensors were used to obtain data for the circadian rhythm/thermoregulation experiment. Motor activity was monitored by a piezoelectric sensor attached to each monkey's jacket. Thermistors attached to the monkeys at three different positions yielded data on skin temperature. Two thermistors attached to the

top and bottom of each primate chair provided ambient temperature values. The Soviets provided additional data on axillary temperature and heart rate. All data required for the experiment were recorded on a self-contained signal processing and digital data storage device. An interface box was used to connect the sensors to the signal processor. A ground readout unit was developed for the experiment to test signal processor operation, initiate data sampling, and recover data from the signal processor. A signal simulator provided simulated biological signals for testing the flight hardware on the ground.

Two magnetic scleral search coils were surgically implanted in the right eye of flight and control monkeys for one of the neurovestibular experiments. Eye movements were recorded preflight and postflight in response to vestibular and optokinetic stimuli provided by a rotator with a three-axis optokinetic stimulator. Recordings of eye movement were made with the animals in an upright position and at several angles of tilt with respect to the gravitational axis of the Earth. The optokinetic stimulator consisted of a light device that projected moving shapes onto a domed screen surrounding the animals' visual field (Fig. 4-45). Movement of shapes at different speeds allowed the animals to be exposed to varying surround velocities. During these preflight and postflight studies, animals were kept in primate chairs with modified head restraint. Eye movement recordings were calibrated by means of an eye coil system. Data were recorded on videotapes and computer disks.

Flight and control monkeys were also implanted with head restraint devices, eye movement electrodes, and neural afferent recording systems. The intent was to measure eye position and discharges from semicircular canal and otolith afferents in response to complex vestibular stimulation. These vestibular parameters were measured periodically during space flight. Vestibular stimulation for preflight and postflight ground studies was provided by rotating the primate chairs on a computer-controlled motor-driven rotator (Fig. 4-46). In flight, preflight, and postflight data were exchanged between the U.S. and the U.S.S.R.

EMG implants were made in the soleus, medial gastrocnemius, and tibilias anterior muscles of the flight and control monkeys by Soviet specialists. Raw EMG data were copied from the Soviet primary data tapes onto tapes provided by the U.S. The U.S. supplied a primate restraint chair and equipment for the postflight muscle biopsy procedure. No experimental hardware was required in flight for the primate metabolism experiment or the rat studies. Ground support equipment for injecting primates with doubly labeled water for the metabolism experiment and for processing and transporting specimens was provided by the U.S.

The U.S. supplied four biotransporters for transferring specimens in temperature-controlled environments. Two of these were thermoelectric units used to move specimens by aircraft from the biosatellite recovery site to Moscow. They were designed to maintain internal temperatures of 23°C and 4°C. In addition, two passive biotransporters were used to maintain specimens at about 4°C and at –70°C during the transfer from Moscow to ARC.

Considerable effort was invested in developing hardware for the radiation dosimetry experiment. Two four-channel ambient temperature recorders were developed for the study. These were small, self-contained, battery-operated units that were mounted on the outside of the spacecraft to measure and record temperature data at pre-selected sampling rates on one to four channels. The data were stored in solid-state memory and readout postflight through a ground-based computer. The remarkable feature of the recorder was its ability to measure temperatures ranging from –50°C to 50°C with an accuracy of ±1°C and a resolution of 0.5°C.

Other hardware required for the experiment included several radiation dosimeters located both external and internal to the spacecraft, and some nuclear track detectors located external to the spacecraft.

Operations

As mentioned previously, there were four types of control experiments performed in support of the in-flight rat studies. Synchronous and vivarium control studies were conducted as in earlier Cosmos flights. A basal control group provided baseline preflight data. A tail suspension control group furnished data in simulated space flight conditions. Small skin, bone, and muscle wounds were surgically created in the hindlimbs of five of the flight rats two days before flight, so that in-flight tissue repair could be studied. At launch, all rats were approximately 14 weeks old. Preflight procedures for the circadian rhythm/thermoregulation experiment consisted of developing and verifying the sensor attachment method, restraint testing of monkeys, sensor implantation, conditioning subjects to skin sensor attachment, and conduct of experiment verification and bioengineering tests. For the neuromuscular

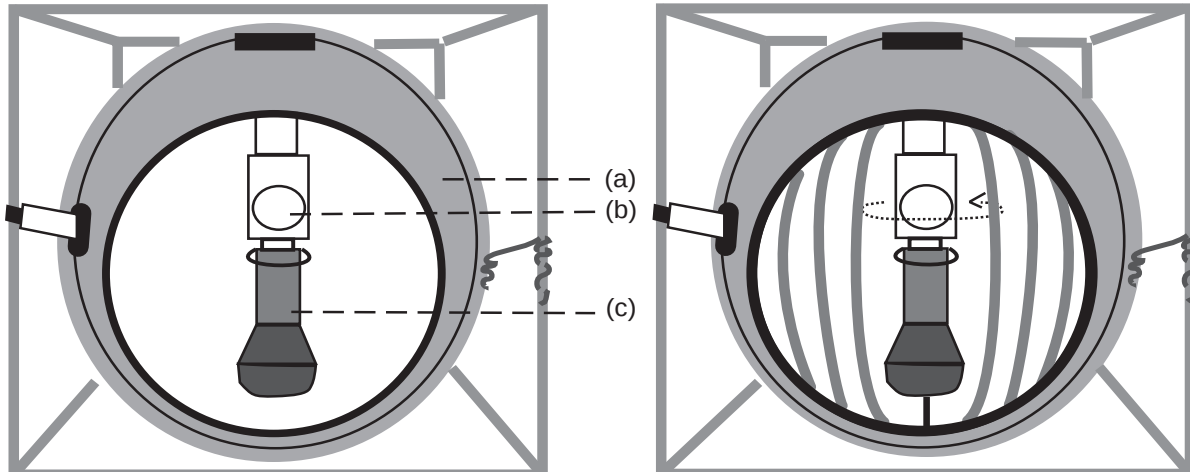


Figure 4-45: The operating principle of an optokinetic stimulator. Stripes are cut out of a ball and a light is placed inside the ball (left). When the light inside is switched on and the ball is rotated, moving stripes are cast on the surrounding wall (right). (a) Chamber cross section with round door opened; (b) light projector; and (c) primate chair.

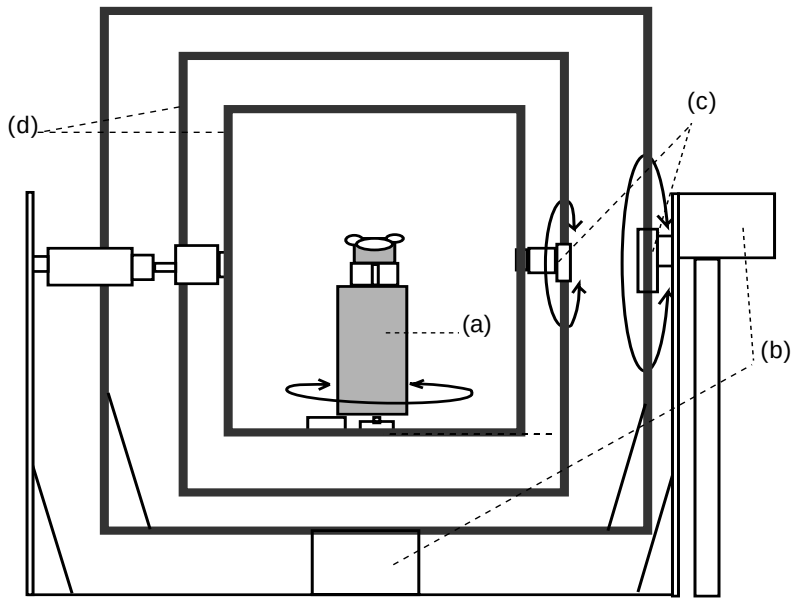


Figure 4-46: The monkey could be rotated along three different axes by the vestibular stimulator using the three different motor/rotor sets. (a) monkey carrier; (b) motor; (c) rotor; and (d) multi-axis rotator.

study, EMG recordings were made and muscle biopsies were taken from non-instrumented limbs. The U.S. scientist in charge of the radiation dosimetry experiment assembled flight and ground control dosimeter units. They were shipped to the U.S.S.R. and mounted inside and outside the biosatellite.

No in-flight data were obtained from the rats flown on the biosatellite other than group measurements of food and water consumption. Combined U.S. and Soviet measurements made on the primates during the in-flight period included skin temperature, axillary temperature, motor activity, heart rate, metabolic rate, EMG activity, recordings of eye and head movements, and nerve activity. The clamshell cover on the dosimeter compartment outside the spacecraft was kept open during launch. Continuous measurements were made during the period spent in orbit. The cover was closed for biosatellite re-entry.

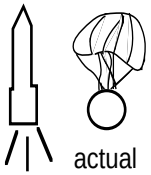
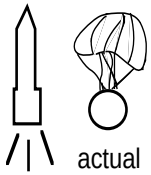
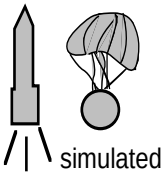
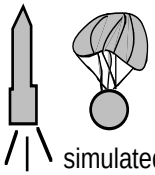
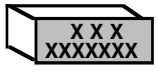
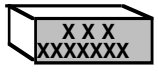
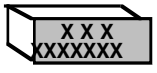
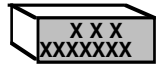
The flight subjects were recovered from the landing site with minimal delay. Flight rats were euthanized between five and eight hours after landing. Rats in all experimental groups were euthanized at the same time of day. Tissues were collected and preserved as stipulated by individual experiments.

Muscle biopsies were taken from the same sites in rats and monkeys, and these data were subsequently compared to biopsies taken from astronauts. Postflight studies were conducted on the monkeys to obtain EMG and neurovestibular data. Immediately after biosatellite recovery, radiation dosimeters were placed in a lead-lined case and transported to Moscow along with the temperature recorders.

Results

Primates

The two flight monkeys tolerated the flight well. An average of 65 percent of the preflight daily food intake was consumed by the

	Flight		Synchronous Control		Vivarium Control		Basal Control (preflight)	Tail-Suspension Control
	Rats	*Monkeys*	*Rats*	*Monkeys*	*Rats*	*Monkeys*	*Rats*	*Rats*
Number of subjects	10	2	10	2	10	2	10	10
Launch/ recovery stress • noise • vibration • acceleration	 actual	 actual	 simulated	 simulated	none	none	none	none
*Food available**	40 grams/ animal/day	500 grams/ animal/day**	40 grams/ animal/day	500 grams/ animal/day**	40 grams/ animal/day	unknown	40 grams/ animal/day	40 grams/ animal/day
Housing	 group housing	 individual capsules	 group housing	 individual capsules	 group housing	 colony cage	 group housing	 individual cages
Environment • temperature • humidity • lighting, etc.	 spacecraft conditions	 spacecraft conditions	 simulated spacecraft conditions	 simulated spacecraft conditions	standard laboratory conditions	standard laboratory conditions	standard laboratory conditions	standard laboratory conditions
Gravitational force	microgravity	microgravity	1 g force	1 g force	1 g force	1 g force	1 g force	simulated microgravity

**Amount actually consumed may be less.*
***A total of 400 grams of juice/day/monkey also available if all psychomotor tasks completed.*
Table 4-11: Cosmos 2044 flight and control rat and monkey experiments.

monkeys during the in-flight period. The lower food intake was thought to be related to a decreased energy expenditure in microgravity.

Rodents

When the BIOS-vivaria unit was opened at the recovery site the rats were active and in good condition. No pathological effects were found in the rats, but changes were seen in various body systems. Regional changes were noted in bone. Plasma levels of calcitonin had decreased and parathyroid hormone levels had increased. Changes found in muscle included decreased mass and fiber cross-sectional area, fewer slow-twitch fibers, and more fast-twitch fibers. Changes were measured in levels of various muscle enzymes and in protein and RNA levels. Cardiac studies showed that a number of changes had occurred in heart structure and chemistry. Changes were also found in hormone levels, metabolism, and the immune, nervous, and reproductive systems. Both muscle and bone repair processes appeared to be inhibited after space flight.

Radiation

For the first time, in-flight temperatures were recorded for radiation dosimeters located outside the biosatellite. These measurements were very useful for interpreting radiation dose data.

Additional Reading

Connolly, J.P., R.E. Grindeland, and R.W. Ballard. *U.S. Monkey and Rat Experiments Flown on the Cosmos 2044 Biosatellite. Final Reports.* NASA TM-108802, September 1994.

Grindeland, R.E., R.W. Ballard, J.P. Connolly, and M.F. Vasques. Cosmos 2044 Mission: Overview. *Journal of Applied Physiology*, vol. 73, no. 2, August 1992, pp. 51–53.

Morey, E.R. Spaceflight and Bone Turnover: Correlation with a New Rat Model of Weightlessness. *Bioscience*, vol. 29, 1979.

Cosmos Missions After 1990

The next mission in the Cosmos biosatellite program was Cosmos 2229, launched in December 1992. A brief outline of the mission is included here.

The Cosmos 2229 spacecraft orbited the Earth for almost12 days. The payload, also designated Bion 10, contained 13 U.S. life sciences experiments. Studies focused on bone, neuromuscular and vestibular physiology, circadian rhythms, and metabolism. Two rhesus monkeys served as experimental subjects on the mission. As on previous Cosmos biosatellite missions, the monkeys were trained to activate food and juice dispensers. In addition, they were trained to operate a foot pedal so that muscle responses could be studied in flight. For in-flight neurovestibular testing, the monkeys were trained to make hand and head movements in response to visual stimuli.

Several of the hardware elements on the biosatellite were improved for Cosmos 2229. The in-flight data recording system was enhanced, making high-quality brain and neuromuscular recordings possible. The monkey feeder system was improved, and a backup juice dispenser was available. The monkey restraint system was modified to allow more arm movement. The neurovestibular data acquisition system was updated through a joint U.S.-Russian development effort, allowing more parameters to be recorded in flight.

Cosmos 2229 was the last designated mission in the Cosmos biosatellite series. The Russian Space Agency and its international collaborators in space life sciences research are presently considering new possibilities for conducting future joint investigations on biosatellites.

Future Programs/Facilities

The U.S., in conjunction with the international space community, is pursuing two different approaches to advance space life sciences research in the coming decades. The first is to establish a more permanent manned presence in space, including biological research facilities. The second is to increase the capability to carry out frequent space biology investigations on unmanned orbiting satellites.

Manned Stations

Long-term investigations must be carried out in space to fully understand biological adaptation to the microgravity environment. Subtle changes have been noted in physiological systems during short-duration space flights, but the implications of many of these changes are not yet clear. Furthermore, the effect of microgravity on life cycles and evolutionary processes can only be investigated by studying multiple generations of organisms.

The future focus of NASA's space life sciences program is driven by its plans to eventually build a space station. International Space Station facilities are being proposed for studies in space medicine and space biology. The intention is to study the consequences of long-term exposure to the space environment and to

permit human habitation in space. Research is expected to be carried out onboard the space station using animals, plants, and humans. The space station may also be used to study biologically important compounds in space and on other planets via remote observation and to study global ecology.

Design and development of the space station is a difficult task for several reasons. From an engineering point of view, there is the primary problem of constructing the station in space. The Space Shuttle may be the means by which equipment and materials are moved from the Earth to the station while it is under construction. From a biomedical point of view, developing medical care for humans inhabiting space for long periods is a real challenge, especially because normal adaptive responses to microgravity must be recognized before illness can be clearly diagnosed. Increased duration flights also raise the need for onboard reclamation and production of air, water and food.

A space station would have to be built in several stages, achieving first a man-tended capability and finally a capability to support a permanent manned presence in space. Such a station may include several pressurized modules. One module could provide a habitat for crew and research personnel, and the others could serve as laboratories. Polar-orbiting platforms for Earth observation could also be included. In later stages of construction, other structures might be added to the station, including an extra support structure for attaching more payloads and platforms moving in the same orbit as the station.

The proposed space station is expected to be an international venture, with several countries contributing to varying degrees. The ESA, Japan, and Canada are involved and Russian participation has been negotiated by President Clinton.

Many ground-based life sciences research facilities at ARC can directly support the space station program. Some scientists investigate the potential effects of space flight on primate vestibular organs in a vestibular research facility. Others use a psychophysiology laboratory to determine the effectiveness of biofeedback to counteract undesirable neurovestibular effects. Still others study human adaptability to altered environmental conditions such as simulated space flight deconditioning in a human research facility. A 20 g human centrifuge is employed to examine the effects of hypergravity on biological subjects, specimens, and instrument packages to qualify them for flight.

A gravitational biology facility is being designed to carry out studies with smaller research subjects under microgravity conditions. ARC is planning to build a centrifuge facility that can be used to study the effects of varying gravitational stimuli on a wide range of research subjects during space flight. Both facilities are proposed for incorporation on a space station.

The U.S. is also planning to carry out research on the Russian Mir space station. This joint U.S./Russian effort is expected to begin in 1995, when the Space Shuttle is scheduled to dock with the Mir Space Station. This joint effort may be a natural step toward an international space station.

Biosatellites

An unmanned free-flyer biosatellite offers several advantages to researchers in the life sciences. One important consideration for gravitational biologists is the ability to achieve a very low gravitational force. It is difficult to attain consistently low levels of acceleration on manned vehicles because many normal operations produce significant accelerations. The quiescent background acceleration in the Space Shuttle amounts to about 10^{-4} g, punctuated by bursts of higher levels. This is of concern to gravitational biologists because the gravity receptor organs of some plant and insect species seem to respond to stimuli even below 10^{-4} g.

NASA has considered several options for flying future experiments on unmanned space vehicles, but a plan has yet to be fully implemented. One possibility is to use a version of the Russian Cosmos biosatellite, modified for longer-duration flight and larger payloads. Whatever concept is eventually selected, such a venture is likely to be an international effort because of the need to pool resources.

Additional Reading

Anonymous. Getting a Payload Aboard Station is Hard Work. *Station Break,* vol. 3, no. 9, November 1991.

Anonymous. *Guide to the Life Sciences Flight Experiments Program.* NASA, unpublished report, July 1984.

Ballard, R.W., et al. *The Reusable Re-entry Satellite: A New Capability for NASA—A Vehicle for International Cooperation.* IAF 89-015, 1989.

NASA. *Life Sciences Research on the Space Station—An Introduction.* NASA TM-86836, September 1985.

Appendix I

EXPERIMENT DESCRIPTIONS

Appendix I: Experiment Description

This appendix contains one-page descriptions of life science experiments developed by the NASA Ames Research Center between 1965 and 1990.

Experiments in this Appendix have been defined based on the science results reported from a given payload, regardless of the number of official "experiments" flown on a given mission. As a result there may be more experiments reported here than defined in the original proposals to NASA. The primary objective is to represent accurately the science produced.

Designations of "Investigator" and "Co-Investigator" are used in these listings to identify appropriate individuals who performed or contributed to the science generally and do not necessarily reflect the utilization of these terms in NASA grants, contracts or investigator proposals. Information was derived from experiment publications and reports (see Appendix II). Due to size limitations, only the first twelve "Co-Investigators" could be listed for each record. Payload managers, payload scientists and other support persons are not listed, although their contribution to the mission(s) which enabled each of these studies should be noted.

Each experiment has been assigned a unique reference number, consisting of:

- a prefix denoting the mission on which the experiment was flown (e.g., C2044, SL3, etc.)
- a numerical designation, unique within each mission e.g., Experiments on Cosmos 2044 would be designated C2044-1, C2044-2 etc.
- related or linked experiments (i.e., conducted under the same proposal) have the same reference number, followed by an additional decimal number (e.g., C2044-17.1 & C2044-17.2), where the first decimal (x.1) indicates the primary experiment, and others (x.2, x.3), secondary

Experiment information sources include:

- publications from the open literature
- NASA internal reports
- sources are listed in Appendix II, Experiment Publications

Each experiment description contains the following: investigators and appropriate institutions; experiment title, discipline area, research subject species and common name, sex; numbers of flight and control subjects used (when appropriate); experiment objectives, method and results; a list of key flight hardware, and where to look in this book for more information. U.S. flight hardware items are described in Appendix III, Flight Hardware. U.S.S.R. flight hardware for Cosmos missions is listed in Appendix III and described briefly in the relevant mission section of the text.

No attempt has been made to identify U.S.S.R. counterparts to U.S. primary investigators (Cosmos only).

Early Program Experiments

Mission ***Page number***

Lists of experiments by discipline and reference number can be found in the mission profiles in Section 4, Programs, Missions and Payloads.

Profile ***Page number***

Gemini 3 / Sea Urchin Egg Package G3-1

Title of Study
Sea Urchin Fertilization and Development

Science Discipline
Cell/Developmental Biology

Investigator	Institute
R.S. Young	NASA-Ames Research Center

Co-Investigator(s)	Institute
Tremor, J. W.	NASA-Ames Research Center
Toxicity Study	
Willoughby, R.	NASA-Ames Research Center

Research Subject(s)
Arbacia punctulata (Sea Urchin Eggs)

8 Specimen Chambers (4 fertilized preflight, 4 inflight)

Ground-Based Controls
8 Specimen Chambers (Syncronous)

Key Flight Hardware
Sea Urchin Egg Package

More Information
Mission p. 36-7; Publications p. 395; Hardware p. 550-51

Objectives/Hypothesis
The objectives of this experiment were to explore gravitational field effect on cells exposed to low gravity conditions and investigate the effects of subgravity on fertilization, cell division, differentiation and growth in a relatively simple biological system. A later investigation was conducted several years later to assess the toxicity of various plastic materials used in flight hardware to sea urchin sperm and unfertilized eggs.

Approach or Method
The specimens in four of the egg chambers were fertilized thirty minutes before launch; specimens in the other four chambers to be fertilized shortly after orbital insertion, twenty minutes after launch. Growth of specimens in each group of eggs was to be inhibited at different stages of development by the addition of a fixative solution: two each of the four chambers fertilized preflight were to be fixed at twenty minutes and one hour ten minutes, respectively; and two each of the chambers fertilized inflight were to be fixed at one hour ten minutes and three hours fifty minutes after launch. Each inflight operation was verified so that the ground-based control experiment could be synchronized with the flight experiment. Cabin temperature and time were recorded for each inflight manipulation.

Results
The experiment was flown and recovered as scheduled. Immediately after recovery, the experiment package was removed and returned to land for comparison of the inflight and ground-based experimental specimens. The experiment objectives were not achieved, primarily for mechanical reasons. The operating mechanism for the package failed, and after mechanical failure, the handle did not actuate the device for the inflight fertilizations/fixations. Also there may have been sufficient leakage from the formalin chambers to result in egg damage. Such problems resulted in an incomplete experiment and in conditions that were prohibitive to accurate interpretation of the portion of the experiment that was completed. Subsequent bio-compatibility studies by a separate investigator have suggested that, while urchin eggs and sperm could be kept safely in hardware made of various plastic materials if open to the air, when the hardware was closed it was found to be toxic to the specimens.

Title of Study
Frog Egg Growth

Science Discipline
Cell/Developmental Biology

Investigator	Institute
R.S. Young	NASA-Ames Research Center

Co-Investigator(s)	Institute
Tremor, J.W.	NASA-Ames Research Center

Research Subject(s)
Rana pipiens (Developing Frog Eggs)

40 Flight Eggs (20 fixed inflight, 20 not examined) Male/Female

Ground-Based Controls
20 Control Eggs; 20 Delayed Flight Control Eggs (Synchronous)

Key Flight Hardware
Rana (Frog) Experiment Package

More Information
Mission p. 38-9; Publications p. 395; Hardware p. 538-9

Objectives/Hypothesis
The objective of this experiment was to determine the effects of subgravity on development in a gravity-oriented biological system, by determining the effect of weightlessness on the ability of fertilized frog eggs to divide normally, and to differentiate and form a normal embryo. The study was only partially completed because of the early termination of the Gemini VIII mission.

Approach or Method
Several dozen frogs were injected with pituitary gland extract 48 hours prior to launch to ensure ovulation at the desired time, and the best eggs from two were selected for flight and fertilized by immersion in a sperm suspension made by maceration of frog testes in spring water. Five eggs were placed in 10 cm^3 of spring water in each of the experimental chambers and maintained at 43 °F to retard cell division until installation in the spacecraft 2.5 hours before launch. Fixative was placed behind leakproof partitions, which when injected into the egg chamber resulted in a 0.5% concentration of formalin. At forty minutes and two hours ten minutes after lift-off, the pilot was to turn the handles on the experiment package, letting the fixative into two of the chambers each time; two other chambers were to be fixed prior to re-entry and the last two left intact. Eggs were studied for gross morphological abnormalities in cleavage planes.

Results
The first fixations were activated correctly (the second was fifteen minutes late), while the mission ended before the later fixation times occurred. Although eggs were fertilized on the ground and exposed space flight only after reaching the two-celled stage, the pre-cooling of the eggs seemed sufficient in retarding cleavage until the microgravity stage of the flight. Early stages of cleavage (2, 8, 16, 32 and 64 cells) were successfully obtained; however, the later cleavage and developmental stages were not reached. Cleavage appeared normal, but studies using centrifuged frog eggs have indicated that the frog egg is most sensitive to gravity during the time between fertilization and first cleavage. While a second flight of this experiment would determine the effect of gravity on later stages of development, technical difficulties in experimental implementation have prevented studies on eggs fertilized in microgravity, before ever having a chance to become oriented with respect to gravity.

Title of Study
Frog Egg Growth

Science Discipline
Cell/Developmental Biology

Investigator	Institute
R.S. Young	NASA-Ames Research Center

Co-Investigator(s)	Institute
Tremor, J.	NASA-Ames Research Center

Research Subject(s)
Rana pipiens (Developing Frog Eggs)

20 Flight Eggs (15 fixed inflight, 5 live)

Ground-Based Controls
20 Control Eggs; 20 Delayed Flight Control Eggs (Synchronous)

Key Flight Hardware
Rana (Frog) Experiment Package

More Information
Mission p. 40-41; Publications p. 395-6; Hardware p. 538-9

Objectives/Hypothesis
In spite of the fact that the frog egg is known to orient itself with respect to gravity during its very early development, preliminary results from Gemini VIII suggest that a gravitational field is apparently not necessary for the egg to divide normally. Although early cleavage stages were successfully obtained during the first flight of this experiment, later cleavage and developmental stages were not reached. The repetition of this experiment on Gemini XII was to provide the desired later cleavage and embryonic stages necessary to complete the study of microgravity effects on developmental processes.

Approach or Method
Frog eggs were prepared analogously to those flown eight months earlier on Gemini VIII; eggs were obtained from female frogs injected with pituitary gland extract, fertilized and placed in egg chambers at 43 °F to retard cell division until installation in the spacecraft. A temperature of approximately 70 °F was maintained at all times during the mission, including during extravehicular activity. At 41 hours after launch, the pilot was scheduled to turn one handle on the experiment package, injecting the formalin fixative into two of the four egg chamber. The other handle was scheduled to be actuated 85 hours into the flight to fix the eggs in one of the remaining two chambers, while the last chamber remained unfixed so those embryos could be recovered alive. All embryos were studied after recovery for gross morphological abnormalities, and histological examination and electron microscopy were preformed.

Results
Results indicated that gravity is not necessary for differentiation and morphogenesis. Postflight analysis indicated that all the phases of the experiment were performed as scheduled and with good results; the desired later cleavage and embryonic stage were successfully obtained to complete the experiment. Ten embryos fixed at 41 hours appeared to be morphologically normal when compared to the ground controls, and no abnormalities were detected by gross observation. Embryos fixed at 85 hours were properly developed and morphologically normal tadpoles. The remaining five embryos left unfixed were found to be well developed, live, swimming tadpoles. Three were morphologically normal and two were abnormal; however, abnormalities were not inconsistent with control embryos and could not be ascribed to development under microgravity conditions. The tadpoles died several hours after recovery for unknown reasons and were fixed for histological sectioning. All such studies indicated normal development.

Title of Study

Genetic Effects of the Space Environment on the Reproductive Cells of Drosophila Adults and Pupae

Science Discipline

Cell/Developmental Biology

Investigator	Institute
L.S. Browning	Rice University

Co-Investigator(s)	Institute
Altenburg, E.	Rice University

Research Subject(s)

Drosophila melanogaster (Fruit Fly)

1 Flight Population, 1 Irradiated Flight Population Male/Female

Ground-Based Controls

1 Flight Backup Population, 1 Irradiation Control Population, 1 Postflight Vibration Control Population

Key Flight Hardware

Drosophila (Fruit Fly) Experiment Package; Radiation Source and Holder

More Information

Mission p. 46-55; Publications p. 396; Hardware p. 486-7, 536-7

Objectives/Hypothesis

This experiment was designed to study possible transmissible genetic damage in the fruit fly caused by exposure to the conditions of space flight combined with continuous ionizing radiation. The large variety of specimens for both stages of maturity and genotype of reproductive cells gave the project an exploratory nature; it was to be followed by careful selection, after return of data, of material most suitable for testing in space.

Approach or Method

Irradiated (^{85}Sr: 1,200-1,500 r) and non-irradiated female adults and larvae were compared with ground controls. Specimens were irradiated only during orbit, and the dose received at the midpoint of space between the surface of the food and the screen in each flight module was calculated from readings on LiF tubes attached to the flight package. Eggs were laid in modules during flight, and those hatching in the first three days after recovery were considered to have been laid when flight conditions might possibly have affected chromosome rejoining during fertilization. Recessive lethal, visible mutations at specific loci, translocations, loss of dominant Y marker, cross-over in males, and nondisjunction were studied.

Results

Increases in recessive lethal frequency and decreases in translocation frequency in mature sperm, and translocations and losses of dominant markers Y^+ and B from the Y chromosome in pupal stage were found in the irradiated flight specimens. In males that were irradiated with 4,000R of x-rays shortly before flight, the frequencies of recessive sex-linked lethals and of translocations were not significantly higher in the flight material than in the concurrent Earth-based controls, but were significantly higher when compared with the concurrent plus the postflight vibration controls. Changes could be attributed to vibration, acceleration, or contamination of the capsule atmosphere with formaldehyde, glutaraldehyde, and ethylene. Therefore there is no obvious direct evidence that weightlessness, either alone or in combination, could produce genetic effects, but neither can it be excluded as an interacting agent with other factors.

Title of Study
Possible Effects of Zero Gravity on Radiation-Induced Somatic Damage

Science Discipline
Radiation/Environmental Health

Investigator	Institute
I.I. Oster	Bowling Green State University

Co-Investigator(s)	Institute
None	

Research Subject(s)
Drosophila melanogaster (Fruit Fly)

1 Flight Population, 1 Irradiated Flight Population Male/Female

Ground-Based Controls
1 Flight Backup Population; 1 Irradiated Control; 1 Postflight Vibration Control

Key Flight Hardware
Drosophila (Fruit Fly) Experiment Package; Radiation Source and Holder

More Information
Mission p. 46-55; Publications p. 396; Hardware p. 486-7, 536-7

Objectives/Hypothesis
To determine to what extent weightlessness may affect the responses of somatic cells to ionizing gamma radiation, immature stages (instar/pupal stages) of the fruit fly were studied in conjunction with space flight and irradiation dose. Highly specialized strains of the fruit fly were developed and later modified to meet the needs of the Biosatellite program.

Approach or Method
Sixty first instar larvae were placed in each of the eight flight modules. Ten first instar larvae with ring chromosomes were selected for cytologic preparations. Additional larvae were added to bring the count to 290. After flight the larvae were examined for visual chromosome changes and some were allowed to develop and breed. The larvae were exposed to a dose of 1,200 to 1,500 r of ^{85}Sr; one unit was shielded. A similar configuration was used on ground controls, with three additional controls being maintained. One important aspect of this experiment was the incorporation of a ring-shaped X chromosome into some of the strands used. In experimental conditions, ring chromosomes can persist as stable entities until subject to breakage, serving to greatly amplify the sensitivity of this system.

Results
Although radiation did increase somatic and reproductive cell mortality, it did so irrespective of whether the larvae had been subject to the particular conditions present during flight (including weightlessness). However, a higher mortality of orbited larvae than ground radiation-exposed larvae was noted with no detectable difference in developmental time. Chromosomes flown and irradiated showed a statistically significant increase in chromosome change over controls. Sex-linked recessive lethals and crossing over were enhanced when the radiation was delivered under conditions of weightlessness. Data suggest that radiation interacts with weightlessness to induce more premature aging and chromosome damage in actively growing and metabolizing specimens than in those irradiated on Earth. Possibly some factor, more than likely weightlessness, is capable of causing improper chromosome separation and formation of chromosome translations.

Title of Study

Mutagenic Effectiveness of Known Doses of Gamma Radiation in Combination with Weightlessness on Wasps

Science Discipline

Radiation/Environmental Health

Investigator	Institute
R.C. von Borstel	Oak Ridge National Laboratory

Co-Investigator(s)	Institute
Smith, R.H.	Oak Ridge National Laboratory
Whiting, A.R.	Oak Ridge National Laboratory
Grosch, D.S.	North Carolina State University
Amy, R.L.	Southwestern University

Research Subject(s)

Habrobracon juglandis (Parasitic Wasp)

Flight Wasps of Various Levels of Irradiation — Male/Female

Ground-Based Controls

Flight Backup Wasps of Various Levels of Irradiation; Constant Temperature Control; Postflight Temperature Control

Key Flight Hardware

Habrobracon (Wasp) Experiment Package; Radiation Source and Holder

More Information

Mission p. 46-55; Publications p. 396-7; Hardware p. 494-5, 536-7

Objectives/Hypothesis

This study was undertaken to survey mature sperm and all stages of oogenesis for mutations, particularly dominant lethality, recessive lethal and visible mutation frequencies, and inherited partial sterility under the combined conditions of radiation and weightlessness.

Approach or Method

Male and female wasps were irradiated preflight, inflight, or not at all with ^{85}Sr at 4,000, 2,000, 1,000, 500, or 0 r. Thirty parameters of genetic, mutational, biochemical, behavioral, and physiological character were measured. Males were analyzed postflight for dominant lethality, recessive lethality, and inherited partial sterility; females were analyzed for total dominant and recessive lethality induced during oogenesis, and for oogonial killing and dominant lethality. Specimens were visually examined for several days postflight for behavioral alterations.

Results

Every animal survived the flight. Flight males were somewhat disoriented in their mating behavior for two days after the flight, while flight females did not appear disoriented in their complex egg-laying and feeding reactions. Space flight effects were enhancement of fecundity and hatchability of primitive and translational oogonia, disorientation of male mating behavior, increased life span of females, and decreased xanthine dehydrogenase activity in males. Radiation effects included decreased hatchability and enhanced fecundity of eggs. The only mutagenic effect was a threefold enhancement of the recessive lethal mutation frequency in the non-irradiated sperm of orbited males. The excess of deaths found among offspring from flown females may have resulted from a mixture of chromosome imbalance phenomena and space-flight-induced recessive lethal mutations. Increased fertilizing capacity appeared to be an enhancing effect of the radiation.

Title of Study
Mutagenic Effectiveness of Known Doses of Gamma Irradiation

Science Discipline
Radiation/Environmental Health

Investigator	Institute
F.J. de Serres	Oak Ridge National Laboratory

Co-Investigator(s)	Institute
Webber, B.B.	Oak Ridge National Laboratory

Research Subject(s)
Neurospora crassa (Microorganism)

1 Flight Culture, 3 Irradiated Cultures (different levels)

Ground-Based Controls
1 Flight Backup Culture; 3 Irradiated Flight Backup (different levels)

Key Flight Hardware
Neurospora (Microorganism) Experiment Package; Radiation Source and Holder

More Information
Mission p. 46-55; Publications p. 397-8; Hardware p. 498-9, 536-7

Objectives/Hypothesis
An experiment exploring the mutagenic effects of known doses of radiation in combination with microgravity on *Neurospora crassa* was first flown on the Gemini XI mission, in 1966. In Gemini XI, conidia were tested on both the surface of Millipore filters and in a colloidal suspension of sugar, and a ^{32}P beta-ray radiation source was used. This experiment was to conduct a similar study on the genetic effects of space flight alone and in combination with known doses of radiation, on the surface of Millipore filters, using a ^{32}Sr gamma-ray radiation source.

Approach or Method
A genetically marked two-compartment heterokaryon, heterozygous for two different genes that control sequential steps in purine biosynthesis, was used. The frequency of radiation-induced recessive lethal mutations, chromosome deletions, and overall survival were studied. A range of radiation exposures was given to determine the dose-response curves.

Results
There was no difference between flight and ground control samples for survival, the overall induction of ad-3 mutations, or for point mutations or chromosome deletions. Gemini XI data show that space flight affected samples on Millipore filters in the same way as on Biosatellite II, with no effect on survival or mutation induction. Gemini *Neurospora* flown in suspension, however, had higher levels of survival and lower frequencies of mutation induction, due to a specific effect on point mutations and not on chromosome-deletion mutations. Through addition postflight experimentation, it was shown that anoxia, which may have occurred inflight, can produce a reduction in the frequencies of both point-mutations and chromosome-deletions. The effects of weightlessness on radiation-induced genetic damage are complex. Both antagonistic and synergistic effects have been found. The results depend on the assay system; in most cases however, the effects are small, twofold to fivefold differences being the usual order of magnitude.

Title of Study

Effects of Weightlessness on the Nutrition and Growth of *Pelomyxa carolinensis*

Science Discipline

Cell/Developmental Biology

Investigator	Institute
R.W. Price	Colorado State University

Co-Investigator(s)	Institute
Abel, J.H.	Colorado State University
Haack, D.W.	Colorado State University

Research Subject(s)

Pelomyxa carolinensis (Amoeba)

24 Flight Chambers (3 ml each)

Ground-Based Controls

24 Flight Backup Chambers (3 ml each); Vibration Control; Variable Temperature Control; Constant Temperature (70 °F) Control

Key Flight Hardware

Pelomyxa (Amoeba) Experiment Package

More Information

Mission p. 46-55; Publications p. 398; Hardware p. 502-3

Objectives/Hypothesis

The study's objectives were to survey the fine structure and distribution of mitochondria, nuclei, nucleoli, Golgi apparatus, and endoplasmic reticulum for changes that may have been induced by weightlessness, and to determine if there were normal growth patterns or normal progression of food vacuole digestion in amoebae subjected to a weightless environment.

Approach or Method

Amoebae were cultured and subcultured, placed in a buffer and fed paramecium. Five units of 24 chambers, each divided into three 5 ml compartments containing either amoebae, paramecium, or fixative were prepared two days before launch. Amoebae were screened and counted as they were selected for chambers. After loading, chambers were filled with a glycine buffer, with a small airspace left. An attempt was made to determine if there was a normal growth pattern or progression of food vacuole digestion, accomplished by both fixing and feeding sin space after variable periods of starvation by means of an activated piston. At recovery, all live organisms were counted and examined for the presence of mitotic forms. Food vacuoles were counted and graded, and the general external morphology of the cell was described.

Results

Amoebae fed normally while in orbit, and specimens fixed in orbit retained the ordinary heteropodial shape. Growth rates of orbited amoebae, both fed and starved, were slower than controls following re-entry and recovery procedures. In continuously fed organisms there was little or no effect of flight detectable in growth rate or actual number of divisions. Electron micrographs showed no abnormalities and few differences between flight and control organisms. Cytochemical data indicate that little or no difference on various digestive processes was produced by weightlessness, acceleration or vibration. Food vacuole data, though, were collected improperly, and little significance can be drawn from them. Growth rates in flight amoebae, although somewhat reduced during flight, appeared to accelerate around the time of re-entry. Results suggest that the weightless environment did not produce any gross irreversible alterations in the normal physiologic processes of the amoebae.

Title of Study

Effects of Weightlessness on the Nuclear and Cellular Division of *Pelomyxa carolinensis*:

Science Discipline

Cell/Developmental Biology

Investigator	Institute
D.R. Eckberg	General Electric Company

Co-Investigator(s)	Institute
Silver, E.C.	General Electric Company
Bushnay, J.L.	General Electric Company
Daniels, E.W.	Argonne National Laboratory

Research Subject(s)

Pelomyxa carolinensis (Amoeba)

24 Flight Chambers (3 ml each)

Ground-Based Controls

24 Flight Backup Chambers (3 ml each); Vibration Control; Variable Temperature Control; Constant Temperature (70 °F) Control

Key Flight Hardware

Pelomyxa (Amoeba) Experiment Package

More Information

Mission p. 46-55; Publications p. 398; Hardware p. 502-3

Objectives/Hypothesis

To study the effects of weightlessness on nuclear and cellular division in a single cell, this study used the giant multi-nucleate amoeba *Pelomyxa carolinensis*. Although this organism appears to be independent of gravity on Earth, it does require a gravitational force to attach to a substrate for locomotion and feeding. When feeding, there is considerable protoplasmic movement which may be independent of a gravitational fields. During mitosis and cell division, however, there is relatively little motion. Since the cell is large with a relatively large nuclei, weightlessness was expected to alter the manner and rate of reproduction.

Approach or Method

Amoebae were cultured and subcultured, placed in a buffer and fed paramecium. Five units of 24 chambers, each divided into three 5 ml compartments containing either amoebae, paramecium, or fixative were prepared two days before launch. Amoeba were screened and counted as they were selected for chambers. Since it was necessary to obtain at least one amoeba fixed during mitosis, about 300 amoebae were required for the flight package. By means of an activated piston, portions of the amoebae were fed and/or fixed inflight. At recovery, organisms were counted and examined for mitotic forms; cell division and plasmotomy rates were determined

Results

There were no significant differences in division rates between flight, clinostat and other control groups. However, there was a trend towards a higher division rate in well fed amoebae during weightlessness. In some cases, growth of the fed amoebae fixed at various times in weightlessness exceeded growth in corresponding chambers on Earth. Nuclear division during weightlessness was synchronous, as in ground controls. No difference was apparent in the postflight cell division rates of the flight group when compared to controls. Flight vibration and acceleration had no observable effect upon nuclear or cellular division.

Title of Study

Effects of Sub-Gravity on Cellular Phenomena of Developing Frog Eggs

Science Discipline

Cell/Developmental Biology

Investigator	Institute
R.S. Young	NASA-Ames Research Center

Co-Investigator(s)	Institute
Tremor, J.W.	NASA-Ames Research Center
Willoughby, R.	NASA-Ames Research Center
Corbett, R.L.	NASA-Ames Research Center
Souza, K.A.	NASA-Ames Research Center
Sebesta, P.D.	NASA-Ames Research Center

Research Subject(s)

Rana pipiens (Leopard Frog Eggs)

120 Flight Eggs (Various Fixation Times)

Ground-Based Controls

120 Flight Backup (Various Fixation Times); 120 Delayed Temperature Control; 120 Constant (70 °F) Temperature Control; 120 Centrifuge

Key Flight Hardware

Rana (Frog) Experiment Package

More Information

Mission p. 46-55; Publications p. 398; Hardware p. 538-9

Objectives/Hypothesis

Developing frog eggs exhibit a marked sensitivity to disorientation with respect to the normal gravity vector. This study investigated the effect of weightlessness on the ability of the fertilized frog eggs to divide, differentiate, and develop normally. Although the original experiment plan called for fertilization of the eggs in space, the experiment was redesigned with fertilization occurring just before launch, due to difficulties in obtaining an acceptable degree of reliability in sustaining egg fertilizability over the expected launch pad hold-time by "freezing." Instead, maintenance at 43 °F would adequately inhibit the first division for fourteen to fifteen hours.

Approach or Method

Three days before launch, sixty female frogs were injected with gonadotrophin to induce ovulation, and two donor frogs were chosen to provide flight specimens. 12.5 hours before launch, stripped eggs were fertilized and divided into clusters of five. Ten eggs each were loaded into the first eight chambers to be fixed, and five eggs each were loaded into the remaining eight chambers. A coolant line around the modules was to maintain a temperature of 42.5 °F to prevent division on the launch pad, until a thermistor was switched to change the temperature to 70 °F at launch. The experiment design called for chamber actuations at Launch (L), L+1 hour, L+2 hours, L+3 (early cleavage), L+32 hours, L+40 hours (late gastrula), and L+68 hours, with the last two chambers remaining unfixed. Multiple temperature and centrifuged ground controls were microscopically compared to flight samples to detect any abnormalities.

Results

The first cleavage, the one most sensitive to gravity, occurred before lift-off, due to a three-hour delay in the Biosatellite launch. Eggs fixed by the second actuation revealed that complete first cleavage was delayed beyond one hour post-launch. All actuations occurred as programmed, except for the last, which was commanded earlier due to the early call-down of the Biosatellite. No differences were observed in abnormalities between flight and ground control eggs; all fell well within the range of expected abnormal development; and the rate of development appeared unaffected. Data suggest that the fertilized eggs divided, differentiated, and developed normally in two days of weightlessness despite initiation of exposure at the middle of the two-celled stage. As with Gemini frog egg experiments, the effect of weightlessness on the initial dividing egg (before two-celled stage) remains yet to be studied.

Title of Study

Induction of Lysogenic Bacteria in the Space Environment

Science Discipline

Cell/Developmental Biology

Investigator	Institute
R.H.T. Mattoni	N.U.S. Corporation

Co-Investigator(s)	Institute
Keller, E.C.	N.U.S. Corporation
Romig, W.R.	University of California, Berkeley
Ebersold, W.T.	University of California, Berkeley
Eiserling, F.A.	University of California, Berkeley

Research Subject(s)

Salmonella typhimurium (Microorganisms)

Escherichia coli (Microorganisms)

1 Flight Culture; 3 Irradiated Cultures (different levels)

Ground-Based Controls

1 Flight Backup Culture; 3 Irradiated Flight Backup Cultures (different levels); 1 Postflight Vibration Control (nonirradiated)

Key Flight Hardware

Radiation Source and Holder; Lysogenic Bacteria Experiment Package

More Information

Mission p. 46-55; Publications p. 398-9; Hardware p. 496-7, 536-7

Objectives/Hypothesis

This study was to test the hypothesis that weightlessness both with or without gamma irradiation would not affect bacterial cell growth or induction of bacterial prophage P-22. The experiment was designed to test the effects of: 1) space flight; 2) three chronic gamma-irradiation dose levels; and 3) temperature.

Approach or Method

The bacteria were used to study the induction of lysogeny, a biological process extremely sensitive to a variety of environmental factors such as vibration and radiation. Free phage and bacterial density were also studied. Nine sets of cultures, each consisting of replicate chambers of 1.4 ± 0.3 ml capacity, were prepared. Each chamber was inoculated with aliquots of a suspension of bacteria adjusted to give mean viable density of about 100 cell/ml. Parameters estimated postflight included: 1) total bacterial density by Coulter principle counting; 2) viable bacterial density by colony count on nutrient agar plates; 3) free P-22 bacteriophage titer by plaque count (PFU) using aliquots of substrate as received; and 4) induced P-22 titer by quantifying PFU following dilution and incubation of recovered viable cells.

Results

Space flight resulted in greater bacterial densities. The factor most likely to be responsible for the higher densities is reduced gravity. *S. typhimurium* also yielded relatively greater densities under gamma irradiation than without radiation. The greater densities after space flight are probably a function of random cell distribution in the liquid medium in reduced gravity. Such distributions would increase the efficiency of the nutrient transfer into and waste transport from the cell. Phage yield decreased with increasing radiation in the space flight cultures. The ratio of phage to bacteria density is consistently lower in flight populations. If the relative number of phage produced per bacterium is constant, then this data indicates that induction is less frequent during space flight.

Title of Study

Synergistic Factors Influencing Embryonic Differentiation and Development of the Flour Beetle

Science Discipline

Cell/Developmental Biology

Investigator	Institute
J.V. Slater	University of California, Berkeley

Co-Investigator(s)	Institute
Buckhold, B.	University of California, Berkeley
Silver, I.L.	Columbia University
Yang, T.C.H.	University of California, Berkeley
Thomas, C.A.	University of Frankfurt

Research Subject(s)

Tribolium confusum(Flour Beetle)

360 Flight; 360 Flight Irradiated

Ground-Based Controls

360 Controls; 360 Irradiated Controls; 360 Capsule Control; 360 Postflight Vibration Control (Synchronous)

Key Flight Hardware

Tribolium (Flour Beetle) Experiment Package; Radiation Source and Holder

More Information

Mission p. 46-55; Publications p. 399; Hardware p. 536-7, 558-9

Objectives/Hypothesis

This experiment studied the direct effect of weightlessness and combined effects of gamma radiation and weightlessness on somatic wing development, germ cells, and the pupal period of flour beetles. From preflight testing, it was found that the predominant abnormality produced was a morphologic, easily recognizable deformation in the size and structure of the membranous wings. Low numbers of these abnormalities were found to occur spontaneously, while at high doses to pupae, almost 100% of the adult animals will develop the abnormality.

Approach or Method

Seven hundred twenty beetle pupae between 19 and 27 hours of age were orbited, half in the presence of ^{85}Sr and half shielded from it. Two-thirds of each pupae group had received a preflight radiation dose (1,350 r) of 180 keV x-rays. Identical ground controls were maintained. It was found that, by choosing an appropriate temperature, the rate of development of the organism could be slowed down or speeded up in such a manner that the organisms could be maintained in pupal stage, so most of the wing development would take place after reaching weightlessness. Upon return, the pupal period, wing abnormalities, and genetic damage were determined by mating experimental beetles with controls. In addition to the Biosatellite controls, a study was conducted to determine if variations could be found from in a different control capsule, as well as a postflight vibration control.

Results

Pupal period, wing abnormalities, and dominant lethality were significantly increased. "Split" mutation increased from ground values of 30% to 45% for flight. Numerically, the vibrated irradiated groups had fewer wing abnormalities than did the appropriate controls, whereas the flight-irradiated sample had more abnormalities than the ground-controls, suggesting that vibration was not the cause of the increased wing abnormalities in flight samples. No differences were detected as a result of the capsule comparison control. Some factor in space flight, probably weightlessness, either facilitated the development of radiation-induced chromosome breaks and/or DNA damage in the meiotic cells (oocytes), or hindered the normal correction of such errors. Another possible explanation is a temperature drop of the flight samples that occurred between separation and retrieval of the flight capsule.

Title of Study
The Liminal Angle of Plagiogeotropic Organ Under Weightlessness

Science Discipline
Plant Biology

Investigator
S.P. Johnson

Institute
North American Aviation

Co-Investigator(s)
Tibbitts, T.

Institute
University of Wisconsin

Research Subject(s)
Capsicum annum (Pepper Plant)

4 Flight Plants

Ground-Based Controls
5 Auxiliary Plants, 8 Clinostat Plants, 4 Irradiated Plants

Key Flight Hardware
Capsicum (Pepper Plant) Experiment Package

More Information
Mission p. 46-55; Publications p. 399-400; Hardware p. 468-9

Objectives/Hypothesis
This experiment was designed to determine if a weightless environment would cause downward curvature of developing leaves and produce results in plants similar to those noted in response to rotation in a horizontal clinostat, i.e., if the liminal angle will be decreased, accompanied by a differential mobilization of carbohydrates and amino acids.

Approach or Method
Four 25-day-old plants were flown and photographed at ten-minute intervals during orbit. Five auxiliary 25-day-old plants were placed inside the flight unit for carbohydrate, amino acid, and nitrogen analyses. The samples prepared for chemical analyses were composed of: 1) leaves from large or prime plants; 2) leaves from small or auxiliary plants; 3) stems from small plants; and 4) growing tips from small plants. Several vibration tests were conducted to determine the effect of the flight launch vibration profile; control plants were also subjected to acoustic levels that simulated the launch and recovery from flight.

Results
A reduction in the liminal angle of the petiole with the stem was found and was similar to that produced using a horizontal clinostat, while the rate of liminal-angle change was slower in the flight plants than those maintained on Earth in the clinostat. Additionally, the duration of the liminal-angle change in the flight plants was more prolonged than in the clinostat controls, thereby resulting in a greater reduction in angles. The carbohydrates were similar in concentration in the control and flight plants, but the amino acid change was greater in the orbited specimens. Carbohydrates, and to some extent, amino acids, play a direct role in the response of plants to geo-induction. The carbohydrates presumably provided the energy for the accelerated growth and/or elongation of the cell along the convex curvature of the plagiogeotropic organ, thereby resulting in a decrease in the liminal angle. It was concluded that the effects of weightlessness can be simulated to a significant degree in the horizontal clinostat.

Title of Study
Emergence of Wheat Seedlings in Zero Gravity

Science Discipline
Plant Biology

Investigator / Institute
C.J. Lyon — Dartmouth College

Co-Investigator(s) / Institute
none

Research Subject(s)
Triticum vulgare (Wheat Seedling)

78 Flight Seeds (less 3 which failed to grow)

Ground-Based Controls
351 Flight Backup Seeds (less 14); 434 Clinostat (less 10); 195 Postflight Vibration Control (less 5); 195 Clinostat-Vibration Control (less 5)

Key Flight Hardware
Triticum (Wheat) Experiment Package

More Information
Mission p. 46-55; Publications p. 400; Hardware p. 560-61

Objectives/Hypothesis
This experiment was to determine whether seeds would produce normal seedlings when germinated in the absence of a significant gravitational force. As the negative geotropism of the coleoptile and the positive geotropism of the roots would be eliminated during flight, seedling organs could be expected to show alterations similar to those produced through a clinostat. Even after only three days growth, measurable differences in coleoptile and primary root orientation should appear in the absence of the even distribution of auxin in these organs by reason of the downward transport of, and equalizing action on, auxin by the force of gravity.

Approach or Method
Seventy-eight wheat seedlings (38-39 mg) were surface sterilized in a 0.05% Hg Cl_2 and soaked for three hours at 95 °F. The seedlings were then placed in polycarbonate stalks containing wet vermiculite. Gas samples were taken and lids were sealed. All growth took place in the dark. Photography was done rapidly at recovery by means of special camera rack systems which included a 45° mirror that reflects the side view of each seedling in the row that is set to face the camera. The orientation of the seedlings was described in quantitative terms by the combination of face-view and side-view angles that are made by the intersection of a line from the tip to the base of a root or coleoptile with a vertical line through the axis of the seedling.

Results
Growth physiology of wheat seed germination and the development of wheat seedlings in their early stages were not disturbed sufficiently by the absence of gravity as reflected in growth rates or external morphology. The stresses of launch acceleration and vibration had no measurable effects on ungerminated wheat seeds. The basic metabolic processes, which supply the energy for normal growth, were apparently undisturbed. This indicates the independence from gravitational force of certain organelles which carry key enzymes to the sites of energy release and use. Weightlessness had no measurable effects on the endogenous mechanisms for production and distribution of the growth hormone, auxin. The wheat seedling proved to be an excellent choice of a small test plant for a space flight experiment in the growth and orientation of plant organs known to be geosensitive. The development and performance of this study led to the discovery of root epinasty, previously unknown to plant physiologists, as a factor in the orientation of plagiotropic roots.

Title of Study

Effects of Weightlessness on the Root and Shoot of Wheat Seedlings

Science Discipline

Plant Biology

Investigator	Institute
S.W. Gray	Emory University

Co-Investigator(s)	Institute
Edwards, B.F.	Emory University

Research Subject(s)

Triticum vulgare (Wheat Seedlings)

78 Flight Seeds (less 3 which failed to grow)

Ground-Based Controls

351 Flight Backup Seeds (less 14); 434 Clinostat (less 10); 195 Postflight Vibration Control (less 5); 195 Clinostat-Vibration Control (less 5)

Key Flight Hardware

Triticum (Wheat) Experiment Package

More Information

Mission p. 46-55; Publications p. 400-01; Hardware p. 560-61

Objectives/Hypothesis

Wheat seedlings were used in this experiment because of the convenient size, their rapid and consistent germination, and their measurable geotropic response. The intention was to determine alterations in the growth and shape of wheat seedling organs, and the reflection of such changes at the cellular level, and to determine if weightlessness is adequately simulated by a clinostat. As the lauch of Biosatellite II entailed considerable vibration, another important aspect of this experiment involved the effect of vibration in the growth and development of the seedlings.

Approach or Method

Seventy-eight wheat seedlings (38-39 mg) were surface sterilized in a 0.05% Hg Cl_2 and soaked for 3 hours at 95 °F. The seedlings were then placed in polycarbonate stalks containing wet vermiculite. Gas samples were taken and lids were sealed. All growth took place in darkness. Measurements of coleoptile height and root length were taken before seedlings were removed from the stalks. Coleoptile diameters were measured by an ocular micrometer on front and side views from photographs taken at recovery. Other parameters of concern to this experiment included germination and survival, pattern of seedling malformations, and consistency of growth, as well as histology of cellular structures.

Results

Inflight germination was unaffected. Wheat seedlings recovered from flight and grown to maturity produced seeds normally. Flight coleoptile height was greater at 58 and 65 hours postflight than controls; possibly the return to normal gravity after orbital flight was the stimulus for this increased growth. Diameters of flight coleoptiles and controls subjected to both vibration and a clinostat were smaller than those subjected to only vibration or the clinostat. Statolith starch granules were randomly distributed. Interphase nuclear volume was greater with fewer early prophase cells. Root cells were longer and random orientation of roots and shoots was noted. Only small deviations from normal physiology or behavior were observed, most of them returning to normal after several hours. The ground control clinostat may be a tool for predicting some of the responses to weightlessness in suitable organisms.

Title of Study
Effects of Weightlessness on the Orientation of Root and Shoot of Wheat

Science Discipline
Plant Biology

Investigator
H.M. Conrad

Institute
Ecological Systems Corporation

Co-Investigator(s)
Johnson, S.P.

Institute
North American Aviation Inc.

Research Subject(s)
Triticum vulgare (Wheat Seedlings)

78 Flight Seeds (less 3 which failed to grow)

Ground-Based Controls
351 Flight Backup Seeds (less 14); 434 Clinostat (less 10); 195 Postflight Vibration Control (less 5); 195 Clinostat-Vibration Control (less 5)

Key Flight Hardware
Triticum (Wheat) Experiment Package

More Information
Mission p. 46-55; Publications p. 401; Hardware p. 560-61

Objectives/Hypothesis
This experiment was designed to: 1) correlate changes in metabolism and energetics with the reorientation of plant organs during weightlessness; 2) to study the key enzymes associated with these processes; and 3) to determine if weightlessness retards any growth of the root and shoot because of a modification of protein synthesis and the incorporation of carbohydrates into cell wall constituents of endosperm of the wheat seedling.

Approach or Method
Seventy-eight wheat seedlings (38-39 mg) were surface sterilized in a 0.05% Hg Cl_2 and soaked for three hours at 95 °F. The seedlings were then placed in polycarbonate stalks containing wet vermiculite. Gas samples were taken and lids were sealed. To determine the extent of root displacement and coleoptile curvature, pictures were taken postflight before the seedlings were divided for analysis. Tissue slices were analyzed for six enzymes, protein content, oxygen consumption, amino acids, and ethylene production. Growth on the clinostat simulated growth in the weightless environment; however only auxin-mediated reactions were simulated on the horizontal clinostat.

Results
The growth of wheat seedlings appeared normal. Increased glucose-6-phosphate dehydrogenase, glyceralderhyde-3-phosphate dehydrogenase, and peroxidase was noted. The increased enzyme activity was found to be physiologic and not due to structural changes in enzymes while in the weightless state. No significant differences were found in the carbohydrate distribution, starch, sucrose, glucose, total or protein nitrogen in endosperms. It was postulated that the orbital flight was not of sufficient duration to elicit a response. If weightlessness did show an effect on metabolism of the endosperm, it would theoretically be one of decreased starch and increased glucose and sucrose; a change in pattern of amino acids would occur, as demonstrated by either an increase or decrease in concentration. The data of these studies indicate that there is a change in the metabolic products of the wheat seedlings, but the altered distribution of these materials over time could not be detected in response to changes in gravitational alterations.

Title of Study

Determination of Influence of Zero Gravity on Mutation Process Using Controlled Gamma Ray Exposure

Science Discipline

Radiation/Environmental Health

Investigator	Institute
A.H. Sparrow	Brookhaven National Laboratory

Co-Investigator(s)	Institute
Schairer, L.A.	Brookhaven National Laboratory
Marimuthu, K.M.	Brookhaven National Laboratory

Research Subject(s)

Tradescantia (Flowering Plant)

32 Flight Plants

Ground-Based Controls

32 Flight Backup Plants, 32 Irradiated Control, 32 Postflight Vibration Control, 30 Clinostat (Irradiated and Nonirradiated)

Key Flight Hardware

Tradescantia (Flowering Plant) Experiment Package; Radiation Source and Holder

More Information

Mission p. 46-55; Publications p. 401; Hardware p. 536-7, 556-7

Objectives/Hypothesis

The plant used in the experiment was a special clone of *Tradescantia* that was heterozygous for flower color and hence useful for easy detection of somatic mutations. These plants are characterized by twelve large somatic chromosomes that are well suited for detailed cytologic analysis. This experiment was to determine the effect of weightlessness and other spacecraft environmental conditions on spontaneous and radiation-induced somatic mutation rates and on selected cytologic changes.

Approach or Method

Thirty-two plants were flown in a package in the spacecraft behind and outside of the radiation shield, and identical nonflight control packages, with and without irradiation, were maintained at the launch site. All plants were observed postflight for: 1) somatic mutation–blue or pink or colorless cells; 2) cell size–giant or dwarf conditions; 3) loss of reproductive integrity–cell death and stunting in stamen hair growth; 4) pollen grain mortality–early and late stages; 5) megaspore development; 6) normal cell divisions; and 7) chromosome aberrations. In order to facilitate computer analysis of the stamen hair, a special scoring technique was developed to "map" or record the frequency and location of mutations, morphological abnormalities, and/or losses of reproductive integrity. Microspores at various developmental stages were fixed and microscopically examined to study micronuclei frequency and the spindle mechanism in the irradiated and nonirradiated cells.

Results

Bud blasting with flower opening was noted eight days post-recovery. Results indicate no effect of space flight factors on spontaneous levels of somatic mutation, pollen abortion, stamen hair stunting, embryo sac abortion, and chromosome aberration. An enhanced deleterious effect in flight samples attributable to weightlessness was noted, however, in the mitotic spindle mechanism in microspores, megaspores, and root tip cells. Irradiated space-flown plants showed an increased pollen abortion, pollen micronuclei, and stamen hair stunting, suggesting increased injury during the more sensitive stages of meiosis and mitosis. The Earth-irradiated group had a higher mutation rate than the flight-irradiated group. Mutation rates were equal for nonirradiated material, with the exception of the pink stamen hair cell mutation, which exhibited an antagonistic response to space flight factors. There was also an increase in flower production by the flight samples through the 26-day postflight scoring period, while no such increase was noted in the clinostat controls.

Title of Study

Monitoring Cardiovascular Function and Performance in the Primate Under Prolonged Weightlessness

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
J.P. Meehan	University of Southern California

Co-Investigator(s)	Institute
Rader, R.D.	University of Southern California

Research Subject(s)

Macaca nemestrina (Pig-Tailed Monkey)

1 Flight Male

Ground-Based Controls

4 Laboratory (Flight Backup Subjects)

Key Flight Hardware

Primate Life Support System; Primate Physiological Sensors

More Information

Mission p. 56-62; Publications p. 401-2; Hardware p. 508-17, 518-9

Objectives/Hypothesis

This portion of the primate mission was to determine the physiological effects of Earth orbit on a nonhuman primate, so as to provide insights into the possible hazards associated with long-term space flight, and to acquire information on basic physiological adjustments to extended weightlessness, particularly concerning the cardiovascular system. The basic premise was that in weightlessness, as a consequence of reduction of the gravitational effect on the long columns of blood in the body, pooling of blood in the large vessels would occur, and that a compensatory mechanism would act to decrease this high blood volume. One indicator of this reflex is the pressure in the large vessels near the heart.

Approach or Method

Inflight vascular pressures were obtained by catheterization techniques. A low power pulsate infusion system maintained catheter patency, and amplification was incorporated to obtain signals compatible with Biosatellite III telemetry. Four indwelling catheters, two venous and two arterial, yielded redundant pressure measurements; additional redundance was obtained by connected tow transducers to each arterial catheter. One pair of electrodes provided electrocardiographic and respiratory information. Heparin pumps were used to keep the catheters clear. Inflight results were compared to the four ground control monkeys, plus the preflight baseline data from the flight monkey.

Results

There was a shift of blood volume to the heart; the flight subject experienced an immediate sustained increase in central venous pressure resulting from a central pooling of blood volume. The observed increase in atrial pressure of 2-3 cm water was large enough to provide a stimulus whereby urine level was initially maintained at a high level, which coupled with a high evaporative fluid loss, produced an early dehydration, probably associated with electrolyte imbalance. Weightlessness and hypothermia acted to shift blood volume centrally, which provided a strong drive for the reduction of blood volume. Restraint, unusual vestibular sensations, and the continuing polydipsia all acted to disturb the central mechanisms which might have acted to restore normal control and regulation of salt and water metabolism. Venous pressure started to fall on flight day five, while arterial pressure and heart rate were within physiologic limits until day eight, i.e. near the termination of the flight.

Title of Study
Investigation of Bone Density Changes in Various Sites of the Skeletal Anatomy of a Primate

Science Discipline
Musculoskeletal

Investigator	Institute
P.B. Mack	Texas Women's University

Co-Investigator(s)	Institute
none	

Research Subject(s)
Macaca nemestrina (Pig-Tailed Monkey)

1 Flight Male

Ground-Based Controls
4 Laboratory (Flight Backup Subjects)

Key Flight Hardware
Primate Life Support System

More Information
Mission p. 56-62; Publications p. 402-3; Hardware p. 508-17

Objectives/Hypothesis
Immobilization associated with flight has been found to definitely be associated with decreases in skeletal density in human subjects in prior studies. Using the x-ray radiographic method, this study was to find changes in bone density that might occur during weightlessness in the non-human primate.

Approach or Method
Several series of bone radiographs were taken preflight to ascertain initial skeletal density in seventeen anatomic sites. The values obtained from scanning sections of bones were equated in terms of mass of calcium hydroxyapatite, the major mineral component of bone. Additional radiographs were also taken postflight.

Results
Postflight density losses at the sites analyzed ranged from -1.71% to -17.52%, compared to 0.12% to -10.72% for ground controls. The bone density losses in the flight animal were considered to be due to immobilization coupled with the aggregate stresses of the flight environment.

Title of Study
Circadian Rhythms of the Pig-Tailed Monkey in Biosatellite III

Science Discipline
Regulatory Physiology

Investigator	Institute
W.R. Adey	University of California, Los Angeles

Co-Investigator(s)	Institute
Hahn, P.M.	University of California, Los Angeles
Hoshizaki, T.	University of California, Los Angeles

Research Subject(s)
Macaca nemestrina (Pig-Tailed Monkey)

1 Flight Male

Ground-Based Controls
4 Laboratory (Flight Backup Subjects); Flight Simulated (to 30 days)

Key Flight Hardware
Primate Life Support System; Primate Physiological Sensors

More Information
Mission p. 56-62; Publications p. 402-3; Hardware p. 508-17, 518-9

Objectives/Hypothesis
The rhythmicity of activity levels, metabolism, excretion rates, thermoregulation, and cardiovascular measures persist in terrestrial laboratory conditions where environmental factors such as light, temperature, and humidity are kept in constant and unvarying conditions. It is believed that if these circadian processes become arrhythmic or desynchronized a deterioration of the organism can result. As the possibility of desynchronosis of the circadian rhythm and its consequences in the space environment is of great concern, this experiment was designed to study the effect of weightlessness on circadian rhythms.

Approach or Method
A variety of parameters measured inflight were analyzed and compared to similarly maintained ground-control subjects in order to determine if desynchronosis occurred. Telemetry included implanted sensors for EEG, EMG, ECG, and respiration, vascular catheters to monitor venous and arterial pressures, temperature sensors in the brain, and general environmental parameters. Computer programs and plotting techniques were used to estimate periodicity. Due to the rapid changes in parameters recorded during the last thirty hours, only 7.5 cycles of 24-hour rhythms were used in analysis from the 8.8-day flight. Day averaging was the most common method: data obtained during the flight were interpolated to fixed 1.5-hour intervals; an average for a four-day period was obtained; and deviations were plotted to give the parameter a cyclic representation. Time displacement of two such tracings was an indication of an altered circadian rhythm.

Results
All physiological sensors functioned well throughout the flight, and the subject displayed a define desynchronosis in some physiological processes. The pCO_2, brain and body temperatures and heart rate were well correlated and indicated a rhythm of greater than 25 hours; however arterial blood pressure remained at 24 hours. Such internal desynchronization of temperature, cardiac, and respiratory cycles from the blood pressure and the external desynchronization from the imposed 24-hour daily routine may have been detrimental to the well-being of the flight subject. The derangement of the cardiovascular system suggested as a concomitant of space flight, and the desynchronization found in the flight subject, may well have acted together to bring about its rapid deterioration. There was no evidence of this desynchronosis in any ground controls, including Biosatellite simulations lasting up to thirty days. This suggests the existence of a gravity dependent mechanism in the control of circadian rhythm.

Title of Study

Sleep and Wake States in Biosatellite III Monkey: Visual and Computer Analyses of Telemetered Electroencephalographic Data

Science Discipline

Neuroscience

Investigator	Institute
W.R. Adey	University of California, Los Angeles

Co-Investigator(s)	Institute
Hanley, J.	University of California, Los Angeles

Research Subject(s)

Macaca nemestrina (Pig-Tailed Monkey)

1 Flight Male

Ground-Based Controls

4 Laboratory (Flight Backup Subjects)

Key Flight Hardware

Primate Life Support System; Primate Physiological Sensors

More Information

Mission p. 56-62; Publications p. 403; Hardware p. 508-17, 518-9

Objectives/Hypothesis

It is well established that the different sleep states are necessary in sufficient quantity for the continuance of physiological and psychological well-being. This circadian rhythm, as well as others, can be perturbed by a variety of factors such as unfamiliar surroundings, selective deprivation, rapid travel across time zones, etc. This study was to investigate the effects of the weightless environment on the sleep and wake states in system of the nonhuman primate.

Approach or Method

Ten EEG, two EOG, and two EMG channels were among the 33 channels of physiological data monitored on Biosatellite III. EEG electrodes were stereotaxically positioned bilaterally in the parietal and visual cortex, the hippocampus, and the amygdala. EOG leads were placed at the right and left outer canthi, and EMG sensors were implanted in posterior cervical and lower scapular sites. Data were telemetered to Earth-based tracking stations at the rate of 22.4 kilobits per second, collected every 97 minutes, and length of capture varied with elevation of spacecraft above the horizon, typically five to seven minutes. The monkey was acclimated to twelve-hour day/twelve-hour night cycle in the capsule.

Results

The sleep of the Biosatellite III primate in orbital flight was abnormal in amount and bizarre in its distribution. It was characterized by rapid transitions in sleep state, brevity of state, and unusual transitions from one state to another. The monkey never achieved its normal terrestrial cycle, and the remarkable fragmentation of consciousness required meticulous and virtually microscopic scoring of EEG records. A dramatic reduction was noted in REM and stage four sleep. Eye movements, normally only seen in REM, were observed during stage two and stage four sleep. The changes began concurrently with the onset of the weightlessness and were not secondary to altered fluid balance or body temperature. There was a complex response to the independent variable of weightlessness, with a sudden decline on day eight attributable to fluid loss and redistribution of blood in the thorax consequent to zero gravity state. The observed fragmentation of consciousness appeared similar to the sleep of medical patients with high cervical cord transections.

Title of Study

Sleep/Wake Activity Patterns of a Pig-Tailed Monkey During Nine Days of Weightlessness

Science Discipline

Regulatory Physiology

Investigator	Institute
W.R. Adey	University of California, Los Angeles

Co-Investigator(s)	Institute
Durham, R.	University of California, Los Angeles
Hoshizaki, T.	University of California, Los Angeles

Research Subject(s)

Macaca nemestrina (Pig-Tailed Monkey)

1 Flight Male

Ground-Based Controls

4 Laboratory (Flight Backup Subjects); 5 Flight Simulated (to 30 days)

Key Flight Hardware

Primate Life Support System; Primate Physiological Sensors

More Information

Mission p. 56-62; Publications p. 403-4; Hardware p. 508-17, 518-9

Objectives/Hypothesis

This portion of the primate experiment was to study the possible effects of the space environment on the sleep/wake cycle of a pig-tailed monkey. This study was to analyze time-lapse photographic records of the animal taken by the on-board camera inside the Biosatellite III capsule. Camera records were taken in conjunction with other physiological measurements on the animal just before and during the flight.

Approach or Method

The 16 mm cameras in the flight and simulated spacecraft were mounted above the left shoulder of the animal. A 24-hour clock and date indicator was placed in the photographic field by an auxiliary lens. Time-lapse pictures were taken at the rate of on frame every twenty minutes at zero, twenty and forty minutes after the hour. Data was obtained by analyzing each frame with an optical data analyzer, in which each frame was taken to represent the animal's state for a given twenty-minute period. Sleep/wake states were defined by the status of the eyes: open, closed, not discernible. Other activities, such as food and water consumption and telemetry data, supplemented the time-lapse data to indicate and verify the animal's sleep or awake state. In addition to the four controls, baseline data from five other monkeys subjected to simulated space flight up to thirty days were also analyzed.

Results

The animal appeared to have began to adapt to space environment within thirty seconds after reaching orbit, when a rapid disappearance of anxiety and struggling could be observed. Lack of sleep in the preceding eighteen hours resulted in immediate sleep. Periods when the subject awoke briefly and drank water were noted, although absent from the time-lapse photographic record. The subject was generally awake during the light cycle, and with the exception of the last two days, the subject tended to remain on a consistent schedule regarding onset of "night" sleep. The sleep/wake cycle was generally 24-hour but a phase angle difference of two hours from the imposed day/night modes and rapid shifts in sleep/ wake states occurred. The subject remained asleep for longer periods of time as the flight progressed. Comparison with other circadian findings indicate that an internal desynchronosis occurred.

Title of Study

Digital Computer Analysis of Neurophysiological Data from Biosatellite III

Science Discipline

Regulatory Physiology

Investigator	Institute
W.R. Adey	University of California, Los Angeles

Co-Investigator(s)	Institute
Walter, D.O.	University of California, Los Angeles
Berkhout, J.I.	University of California, Los Angeles
Buchness, E.	University of California, Los Angeles
Kram, E.	University of California, Los Angeles
Rovner, L.	University of California, Los Angeles

Research Subject(s)

Macaca nemestrina (Pig-Tailed Monkey)

1 Flight Male

Ground-Based Controls

4 Laboratory (Flight Backup Subjects)

Key Flight Hardware

Primate Life Support System; Primate Physiological Sensors

More Information

Mission p. 56-62; Publications p. 404; Hardware p. 508-17, 518-9

Objectives/Hypothesis

Two goals were formulated for computer analysis of Biosatellite III data: 1) a short term analysis to assist in animal monitoring and mission abort decisions and 2) a long-term analysis to support the general physiological studies, including circadian rhythm studies. Down-linked data for short-term analysis were available from telemetry captures at prime receiving stations in Quito, Ecuador; Lima, Peru; Santiago, Chile; and Fort Myers, Florida. Data for long-term analysis were available from the prime stations and many others following flight.

Approach or Method

Spectra and coherences were presented principally in the form of contour maps which compress much data into brief compass. Transient changes in the animal's responsive states, circadian rhythms in neuro-electric parameters, and the general course of EEG are represented in one, highly compressed set of maps. Short term analysis and transmission of output graphs to Mission Control was initiated within seven hours of the data's generation in space. A composite map of EEG spectral intensity contours from insertion of the animal into the capsule to de-orbit was obtained by plotting contours across 180 data-capture epochs occurring at irregular intervals approximately 1.5 hours apart. In this mapping, the left parietal cortex was representative of the four cortical channels, and the left amygdala was representative of the six deep bipolar leads. A total of 46,270 seconds of "long-term" data was processed in ten-second epochs, for these and other maps.

Results

Launch was a mildly traumatic event for the animal, intensity contours show alterations during the two hours immediately following launch, then return to stable, prelaunch levels. Visible spectral peaks on the left parietal channel on days two, three, four, and five suggest that the animal was aroused during performance tasks, although the actual performance was quite low. The animal appears to have had a functionally intact cortex until flight day six, and to have had a functional cortical impairment on flight days seven and eight. This was compatible with a minimal response to alterations of light versus dark and with maintenance of normal subcortical electrical activity. The animal became grossly pathological and unresponsive on flight day nine, when the mission was terminated. Considerable fluctuations in spectral intensity persisted within certain frequency bands. This pathological state resembled, but was not identical with, a state of acute hypothermia under anesthesia. Death occurred eight hours after recovery, the acute cause being ventricular fibrillation.

Title of Study

Urine Excretion Rates of Calcium, Creatine, and Creatinine in the Test Monkeys and Flight Monkey Used for Biosatellite III

Science Discipline

Regulatory Physiology

Investigator	Institute
N. Pace	University of California, Berkeley

Co-Investigator(s)	Institute
Grunbaum, B.W.	University of California, Berkeley
Kiepert, D.W.	University of California, Berkeley
Rahlmann, D.F.	University of California, Berkeley
Smith, G.D.	University of California, Berkeley
Rho, J.H.	Jet Propulsion Laboratory
Spaeth, E.A.	Jet Propulsion Laboratory

Research Subject(s)

Macaca nemestrina (Pig-Tailed Monkey)

1 Flight Male

Ground-Based Controls

4 Laboratory (Flight Backup Subjects)

Key Flight Hardware

Primate Life Support System; Urine Analyzer

More Information

Mission p. 56-62; Publications p. 404; Hardware p. 508-17, 514-5

Objectives/Hypothesis

Among other Biosatellite III objectives, the urine analyses, together with appropriate analysis of feces and a knowledge of quantity and composition of food, were to permit computation of the calcium balance of the animal in weightlessness, thereby allowing assessment of the degree of possible skeletal demineralization. Also, measurement of the excretion rate of creatinine and creatine was expected to shed some light on the question of whether or not significant disuse atrophy of the musculature occurs as a consequence of space flight.

Approach or Method

The flight Urine Analyzer included a case which contained a urine sample accumulator, a calcium analyzer, a creatinine-creatine analyzer, reagent storage bags, logic sequencers, a data handling system and a power converter. Once every six hours during flight urine sample aliquots were analyzed and telemetered to the ground and correlated with laboratory animals. Collections for flight and control animals began seventeen days preflight, and continued through flight termination. Bladder and vascular catheters were surgically implanted thirteen, twelve, and eight days preflight.

Results

Three of the flight candidate animals, including the flight animal, experienced a profound hypocalciuria in association with the preflight surgery, which was transiently reversed but then recurred ten to fourteen days after initial occurrence. This obscured any possible effects of weightlessness on urine calcium excretion rate in the flight animal. On a more positive side, the development of a fully automated urine analyzer which permitted continuous measurement of these three substrates (calcium, creatinine, and creatine) during the flight ranks as an outstanding accomplishment. Other results suggest that while anorexia occurred in the flight monkey, there was no evidence of diuresis, and that the urine excretion rate of creatinine is depressed in monkey and man, in the weightless state.

Title of Study
Effects of Cosmic Particle Radiation on Pocket Mice Aboard Apollo 17

Science Discipline
Radiation/Environmental Health

Investigator	Institute
W. Haymaker	NASA-Ames Research Center

Co-Investigator(s)	Institute
Look, B.C.	NASA-Ames Research Center
Winter, D.L.	NASA-Ames Research Center
Benton, E.V.	University of San Francisco
Cruty, M.R.	University of San Francisco

Research Subject(s)
Perognathus longimembris (Pocket Mouse)

1 Flight Female; 4 Flight Males — Male/Female

Ground-Based Controls
5 Flight Backup

Key Flight Hardware
BIOCORE: Life Support Hardware; Pocket Mouse Radiation Dosimeter

More Information
Mission p. 71-5; Publications p. 404; Hardware p. 462-5

Objectives/Hypothesis
The objective of the BIOCORE experiments were to determine whether a specific portion of the high Z energy (HZE) galactic cosmic ray particle spectrum, especially particles with Z no less than six, can produce microscopically visible injuries in the brain, eye, and other tissues.

Approach or Method
Two canisters were prepared with five pocket mice in each. One canister was used in the flight experiment; the other was used as a ground control, undergoing the same stress as the flight canister. Flight mice were implanted with plastic dosimeters underneath the scalp. The mice were sacrificed postflight. The heads were fixed and sliced into 1,600 sections each, and compared with the similarly sectioned heads of the control mice (which had paper dosimeters placed on their heads, and holes drilled to simulate the HZE particle paths that were encountered by the flight mice). Flight cosmic ray particles were recorded in the five dosimeters, which probably recorded 50% of the hits through the brain.

Results
Four of the five mice returned alive; two in good, active condition, two subdued and hunched up. The body tissues of the four live mice showed no change due to HZE. The olfactory epithelium was severely damaged in four of the mice, less severely in the other. Both flight and control mice showed hemorrhaging in the middle ear cavity bilaterally. Although there were thirteen tiny lesions in the scalps of three flight mice, there were no pathological changes to the brain meninges or calvarium. Five particles were recorded through the eyes, but no retinal lesions were found. Although detailed studies were performed in an effort to discover whether HZE particles are injurious to brain and other tissue, the absence of lesions does not negate this possibility.

Title of Study

Effects of Cosmic Particle Radiation on the Calvarium, Brain, and Meninges

Science Discipline

Radiation/Environmental Health

Investigator	Institute
W. Haymaker	NASA-Ames Research Center

Co-Investigator(s)	Institute
Zeman, W.	Indiana University
Turnbill, C.E.	NASA-Ames Research Center
Clayton, R.K.	NASA-Ames Research Center
Bailey, O.T.	Abraham Lincoln School of Medicine
Samorajski, T.	Texas Medical Center at Houston
Vogel, F.S.	Duke University
Lloyd, B.	Duke University
Cruty, M.R.	University of San Francisco
Benton, E.V.	University of San Francisco
Kraft, L.M.	NASA-Ames Research Center

Research Subject(s)

Perognathus longimembris (Pocket Mouse)

1 Flight Female; 4 Flight Males (3 live)

Ground-Based Controls

17 Trajectory Controls (tracked mice)

Key Flight Hardware

BIOCORE: Life Support Hardware; Pocket Mouse Radiation Dosimeter

More Information

Mission p. 71-5; Publications p. 405; Hardware p. 462-5

Objectives/Hypothesis

The stopping point region of a cosmic ray particle, Bragg peak, has the greatest potential for injury of the brain or other tissue because it is here that the particle's LET reaches a maximum. Because an acute inflammatory reaction was observed in two monkeys within a few days after balloon flights, the decision was made to process the mice as soon as they were recovered. It was realized, however, that a considerable proportion of the acute inflammatory cells would disappear, if evoked earlier in the mission; the lifetime of these cells in tissue is no more than five days.

Approach or Method

Two canisters were prepared with five pocket mice in each. Heads of flight mice and seventeen control mice that had been "tracked" in the trajectories of cosmic ray particles were serially sectioned, from anterior to posterior, in the coronal plane at 10 µm, yielding 1,200 sections per animal. In the event that, during the search, a lesion was found in the brain of a flight animal, the "tracked" section from the same level of the brain of a control mouse was examined to see if the lesion and "tracked" hole would correspond. To ascertain whether differences existed regarding the numbers of mitotic figures in the ependyma and in the dentate gyrus of the hippocampal formation, an enumeration of metaphase figures in these regions was undertaken.

Results

A concentrated search was made of the flight brains and meninges for lesions of cosmic ray origin, but no evidence of injury was found. In one flight mouse, however, were sizable congregations of polymorphonuclear leukocytes in the region of the inferior sagittal sinus. Judging from findings in the "tracked" control mouse, a heavy or very heavy particle having a declination angle of 47.1° through the cerebrum passed within 0.4 mm of this sinus. Mitosis in the dentate gyrus of the hippocampal formation was considerably reduced in comparison with that in control animals. Several variables may have caused negative findings in the flight brains, including size of the brain, limitations imposed by dosimeters, and the attenuation of particles of high LET by spacecraft or animal canister shielding. Since the animals were exposed primarily to HZE cosmic ray particles at the lower end of the light LET spectrum, the lack of observable changes cannot be taken as evidence that the brain will suffer no damage from the heavier HZE particles on prolonged manned missions.

Title of Study

Effects of Cosmic Particle Radiation on the Scalp

Science Discipline

Radiation/Environmental Health

Investigator	Institute
F.S. Vogel	Duke University Medical Center

Co-Investigator(s)	Institute
Lloyd, B.	Duke University Medical Center
Cruty, M.R.	University of San Francisco
Benton, E.V.	University of San Francisco

Research Subject(s)

Perognathus longimembris (Pocket Mouse)

1 Flight Female; 3 Flight Males — Male/female

Ground-Based Controls

17 Trajectory Controls (tracked mice); 1 Unimplanted Control; 1 Flight Backup

Key Flight Hardware

BIOCORE: Life Support Hardware; Pocket Mouse Radiation Dosimeter

More Information

Mission p. 71-5; Publications p. 405; Hardware p. 462-5

Objectives/Hypothesis

Certain cellular components of the skin are known to be sensitive to conventional radiation, and there is evidence to suggest that these components might be altered by radiation from high-energy galactic cosmic ray particles. The objective of this study was to pursue the problem further by studying the scalps of mice flown on Apollo 17. However, while subscalp monitoring for cosmic ray particles allowed a check of correspondence between particle tracks in the dosimeters and any scalp lesions, the dosimeter itself is a foreign body which would expect to induce cellular and tissue reactions.

Approach or Method

Two canisters were prepared with five pocket mice in each. One canister was used in the flight experiment; the other was used as a ground control, undergoing the same stress as the flight canister. Flight mice were implanted with plastic dosimeters underneath the scalp. The scalps of the four mice that survived the flight and two controls were fixed, embedded, and serially sectioned to 8 µm in the coronal plane. Stained sections were examined microscopically at 450x. A rectangular portion of skin was removed from the lower lumbar region of the back of one flight mouse to serve as an added control against any nonspecific trauma resulting from the dosimeter. Comparisons between the length of the dosimeter and total thickness of the 8 µm sections, and between dosimeter width and the dermal indentations along the dosimeter edges, suggested that an 8% scalp shrinkage had occurred during histological processing.

Results

Only minor alterations were found in the scalp of the non-implanted control, while two epidermal lesions were identified in the flight backup. However, the absence of leukocytes served to distinguish this tissue reaction from reactions regarded as due to lesions in flight animals. The lesions detected only in the flight scalps were of a necrotic nature with regard to the epidermis and hair follicles, and acute inflammatory cells could be found in the dermis and the subcutaneous tissue as well. Similarities between lesions in the scalp and removed skin suggest that the area not exposed to the dosimeter had received comparable focal injuries during space flight. The number of scalp lesions and number of tracks in dosimeters varied notably, though, thirteen lesions as opposed to 76 tracks. In explanation of this difference, it was suspected that lesions, if initiated by cosmic ray particles early in the flight, would have reached a state of advanced repair by recovery, while if such a trajectory was coincident with the dosimeter, it would be permanently recorded.

Title of Study

Effects of Cosmic Particle Radiation on the Nasal Mucosa

Science Discipline

Radiation/Environmental Health

Investigator	Institute
L.M. Kraft	NASA-Ames Research Center

Co-Investigator(s)	Institute
Vogel, F.S.	Duke University Medical Center
Lloyd, B.	University of San Francisco
Benton, E.V.	University of San Francisco
Cruty, M.R.	University of San Francisco
Haymaker, W.	NASA-Ames Research Center
Leon, H.A.	NASA-Ames Research Center
Billingham, J.	NASA-Ames Research Center
Turnbill, C.E.	NASA-Ames Research Center
Teas, V.	Cleveland Psychiatric Institute
Look, B.C.	NASA-Ames Research Center
Suri, K.	NASA-Ames Research Center

Research Subject(s)

Perognathus longimembris (Pocket Mouse)

1 Flight Female; 4 Flight Males (3 live) Male/female

Ground-Based Controls

17 Trajectory Controls (tracked mice); 7 Untreated; 4 Flight Backup; 6 Environmental ($K0_2$) Controls

Key Flight Hardware

BIOCORE: Life Support Hardware; Pocket Mouse Radiation Dosimeter

More Information

Mission p. 71-5; Publications p. 405; Hardware p. 462-5

Objectives/Hypothesis

A totally unexpected result of the Apollo 17 flight was the appearance in all of the flight animals of profound alterations of the olfactory epithelium, while the epithelium of the control animals remained entirely normal. The alterations consisted of "disarrayed" olfactory epithelium, on the one hand, and of disseminated discrete lesions, on the other. This investigation was undertaken in an effort to elucidate possible causes of the alterations.

Approach or Method

Two canisters were prepared with five pocket mice in each. One canister was used in the flight experiment; the other was used as a ground control, undergoing the same stress as the flight canister. In addition, several control mice exposed to increased oxygen partial pressure in $K0_2$ tests during hardware verification were also examined. Histological sections were prepared from whole-head mounts and sectioned in the coronal plane. Camera lucida drawings were made at intervals of 80 µm to ascertain the topography of the olfactory and respiratory mucosa and record the location and character of lesions. Lesion dimensions were determined by an optical micrometer and shapes inferred from composites of 10 µm serial sections. Areas of olfactory and respiratory regions were calculated; volume and surface area covered by olfactory epithelium were also determined. By multiplying the dosimeter particle flux by the planar target area of the mucosa, it was possible to obtain an estimate of the number of HZE particles which passed through the mucosa.

Results

The olfactory epithelium, but not the nasal respiratory epithelium, of the four mice that survived the flight showed both diffuse alterations and numerous disseminated focal lesions. The olfactory mucosa of the mouse that died inflight was also affected, but to a minor degree insofar as could be detected. A number of possible causes was considered: systematic or regional infection; inhaled particulate material (seed dust); by-products from the KO_2 bed in aerosol or particulate form; gas contaminants originating in the flight package; volatile substances from the dead mouse; weightlessness; and cosmic particle radiation. Of these only the latter two seem likely as a result of control studies. It would be necessary to invoke the whole spectrum of radiation as causative if cosmic radiation were to be the cause. It was also noted that a Lunar Neutron Probe containing U^{235} was located in the locker next to the flight package; however, neutrons from this source have insufficient energy to penetrate the flight package.

Title of Study

Effects of Cosmic Particle Radiation on the Ear

Science Discipline

Radiation/Environmental Health

Investigator	Institute
W. Haymaker	NASA-Ames Research Center

Co-Investigator(s)	Institute
Leon, H.A.	NASA-Ames Research Center
Barrows, W.F.	NASA-Ames Research Center
Suri, K.	NASA-Ames Research Center
Kraft, L.M.	NASA-Ames Research Center
Turnbill, C.E.	NASA-Ames Research Center
Webster, D.B.	Louisiana State University
Ashley, W.W.	NASA-Ames Research Center
Look, B.C.	NASA-Ames Research Center
Simmonds, R.C.	NASA-Ames Research Center
Cooper, W.	Northrup, Inc.
Platt, W.T.	NASA-Ames Research Center

Research Subject(s)

Perognathus longimembris (Pocket Mouse)

1 Flight Female; 4 Flight Males (3 live) Male/female

Ground-Based Controls

17 Trajectory Controls (tracked mice); 5 Untreated; 4 Flight Backup; 3 Environmental ($K0_2$) Controls; 3 Implanted Controls

Key Flight Hardware

BIOCORE: Life Support Hardware; Pocket Mouse Radiation Dosimeter

More Information

Mission p. 71-5; Publications p. 405-6; Hardware p. 462-5

Objectives/Hypothesis

Hemorrhage had occurred in the middle ear cavity of mice subjected to increased oxygen partial pressure in $K0_2$ tests during hardware verification, and hemorrhage and/or exudative materials were noted in all flight and flight backup mice. The main objective was to determine if hemorrhagic materials in the middle ear cavities and the cellular reaction thereto differed in any way in the flight animals compared to the flight backup controls. This study was also to investigate if the otoconial apparatus of mice flown on Apollo 17 had been altered as a result of weightlessness, and to determine whether any structures of the inner ear had been injured by cosmic ray particles.

Approach or Method

Two canisters were prepared with five pocket mice in each. One canister was used in the flight experiment; the other was used as a ground control, undergoing the same stress as the flight canister. In addition, several control mice exposed to increased oxygen partial pressure in $K0_2$ tests during hardware verification were also examined. Examinations were conducted at a rostral level of the middle ear. Heads were decalcified, embedded, serially sectioned to 10 µm, and stained; the second section (of eight) on every fourth slide throughout the middle ear cavity was examined. Criteria were established to evaluate the findings from the middle ear cavity based on histological features of linings in untreated animals. To sample leukocytic response quantitatively in a manner that would introduce the least bias, the procedure was adopted to start counting air cells that contained hemorrhagic materials (i.e. plasma, protein material, blood clots, unidentified remnants of exudative material).

Results

No evidence was found that the inner ear had been damaged, although poor fixation precluded a detailed study. The distribution of hemorrhagic materials in flight and flight backup middle ear cavities differed from animal to animal in both groups. Extraneous factors that might be held accountable for the occurrence or nonoccurrence of hemorrhage would include the amount of food in the mouth or being swallowed at the of pressure excursion and the degree of responsiveness of the mouse to autoinflation of the middle ear cavity. Either the active feeding state or torpor could be expected to influence the patency of the nares and Eustachian tubes at the time of pressure excursion. There was no increase in leukocyte population along the paths of the 23 cosmic ray particles registered as traversing the middle ear in the dosimeters. The increased exudation and the greater response by leukocytes in the flight mice may have been causally related to the lesions found in their olfactory mucosa, but there was no data in support of this possibility.

Title of Study
Effects of Cosmic Particle Radiation on the Eye

Science Discipline
Radiation/Environmental Health

Investigator	Institute
D.E. Philpott	NASA-Ames Research Center

Co-Investigator(s)	Institute
Corbett, R.L.	NASA-Ames Research Center
Takahashi, A.	Kanazawa University, Japan
Benton, E.V.	University of San Francisco
Cruty, M.R.	University of San Francisco

Research Subject(s)
Perognathus longimembris (Pocket Mouse)

1 Flight Female; 4 Flight Males (3 live) Male/female

Ground-Based Controls
17 Trajectory Controls (tracked mice); 5 Flight Backup; 4 Untreated

Key Flight Hardware
BIOCORE: Life Support Hardware; Pocket Mouse Radiation Dosimeter

More Information
Mission p. 71-75; Publications p. 406; Hardware p. 462-5

Objectives/Hypothesis
Various types of "light flashes" had been seen by astronauts on previous Apollo missions. This experiment was to explore for the first time the question of the radiobiological hazard posed to the retina from cosmic ray particles. The objective of this study was to derive preliminary information on the risk to the human retina from the passage of cosmic ray particles through the eyes in the course of deep space missions. No method was incorporated to ascertain whether light flashes were produced in the mouse eyes. However, the astronauts themselves observed several flashes.

Approach or Method
Two canisters were prepared with five pocket mice in each. One canister was used in the flight experiment; the other was used as a ground control, undergoing the same stress as the flight canister. Most of the eyes were left *in situ* and serial sectioned at 10 µm with the head. Right eyes from two flight mice were fixed and serially sectioned at 2 µm and the resultant 1,550 sections were mounted on glass slides. Some 2 µm sections were examined by phase contrast, while others were stained and then examined. Other sections cut at 400-500 A were stained with uranyl acetate and lead citrate and studied under an electron microscope.

Results
In the four surviving mice, a total of five cosmic ray particles which had registered in the dosimeters had trajectories that intersected the eyes. Four of them (Z=6-9 for three and Z 10 for the fourth) most likely went through the head before reaching the dosimeter, while direction of the fifth was indeterminable. Lack of any observable lesion in the retina could be attributed either to the very small probability of a particle's Bragg peak being so thin a target as the retina to insufficient particle energy loss in the retina. While it is not known whether the traversal of the retina by cosmic ray particles yielded enough excitation energy to produce light flashes in the flight mice, it appears there was less energy deposition in the retina than was required for a particle to produce retinal damage. For the five trajectories identified, the LET in the retina would be less than the LET in the dosimeter; on average LET in the retina would have been £200 keV/µm. Results from accelerator studies have shown retinal damage only when the Bragg peak, a much higher LET region, was in or near the retina.

Title of Study

Orbiting Frog Otolith Experiment: Preliminary Results

Science Discipline

Neuroscience

Investigator	Institute
T. Gualtierotti	University of Milan

Co-Investigator(s)	Institute
Bracchi, F.	University of Milan
Rocca, E.	University of Milan

Research Subject(s)

Rana catesbeiana (Bullfrog)

2 Demotorized Frogs (periodically centrifuged) Male

Ground-Based Controls

Flight Simulation Control (2 Frogs); Laboratory Baseline Controls

Key Flight Hardware

Frog Otolith Experiment Package (FOEP); FOEP Life Support System (LSS)

More Information

Mission p. 65-7; Publications p. 406; Hardware p. 490-93

Objectives/Hypothesis

Space flight has created a condition of total alteration of the normal input to the balance receptors, including those of the otolith organ, the portion of the inner ear which controls balance with respect to the excitation of gravity. This is thought to be responsible for the space motion sickness or air sickness syndrome that may accompany flights on both planes and spacecraft. The OFO-A mission was prepared as part of a special program of vestibular physiology with the purpose of studying the way in which gravitational pull affects vestibular function. This experiment was to obtain information concerning the response of the basic acceleration sensor mechanism (hair cells of the otolith organ) in weightlessness.

Approach or Method

Two bull frogs were completely immersed in water. Action potentials were recorded from four vestibular nerve fibers corresponding to the gravity sensors of the inner ear. The design of the satellite kept inflight acceleration to a maximum of 10^{-3} g, and an onboard centrifuge could periodically produce up to 0.6 g of stimulation. Spike train data patterns recorded during orbital flight and ground control experiments were compared to determine any alterations in the basic activity of vestibular cells. EKG was continuously monitored as a vital index of the animals' condition. Centrifuge operation was preplanned for the first day of flight, after which it was carried out according to an experiment routine chosen on the basis of preceding results.

Results

EKG showed the same characteristics as on the ground; probably submersion in water was responsible for minimizing the impact of lift off. During the first nine hours and up to the 46th hour of weightlessness, the firing at rest slowed down so that the average interspike interval was more than four times longer in duration than on the ground. A rebound effect was observed starting around the 48th hour and reaching its climax after the 72nd hour with a spontaneous firing twice as fast as that observed in 1 g. Although there was some time shift between specimens, the general response pattern to the centrifuge was similar: a decrease beginning after the third day, and a return to normal by day five. The responses during the first few days suggest an inability to distinguish between zero input and maximum input during this period, i.e., the receptors were not functioning. A trend towards normalization was observed following this stage of maximum alteration. Results indicate only a partial adaptation of basic neural control process to weightlessness while some alteration remains.

Title of Study

Orbiting Frog Otolith Experiment: Secondary Spike Analysis

Science Discipline

Neuroscience

Investigator	Institute
T. Gualtierotti	University of Milan

Co-Investigator(s)	Institute
Bracchi, F.	University of Milan
Morabito, A.	University of Milan
Esposti, D.	University of Milan
Crossignani, P.	University of Milan

Research Subject(s)

Rana catesbeiana (Bullfrog)

2 Demotorized Frogs (periodically centrifuged) Male

Ground-Based Controls

Flight Simulation Control (2 Frogs); Laboratory Baseline Controls

Key Flight Hardware

Frog Otolith Experiment Package (FOEP); FOEP Life Support System (LSS)

More Information

Mission p. 65-7; Publications p. 407; Hardware p. 490-93

Objectives/Hypothesis

During the OFO-A data analysis it appeared evident that the technique initially used for data reduction, based on visual appraisal of spikes and voltage level clipping, was completely inadequate and impossibly time consuming. Moreover, it was evident that some information was lost, such as smaller spikes in the data stream. This study was to further the investigation of frog vestibular function in microgravity by development of automatic analysis of the spike train data and recognition of secondary spikes. Analysis of the additional, smaller action potentials constantly appearing in telemetry channels would noticeably increase the amount of information obtained by the orbital experiment.

Approach or Method

A technique capable of automatic analysis of the rough multispike train data was developed, based on spike shape discrimination and taking into account the minimum number of amplitude and temporal parameters of each spike. A three-channel apparatus was built which allowed the simultaneous reading of three different spike potentials from the same electrode. The minimum number of amplitude and temporal parameters necessary to unequivocally recognize the spike potential was determined, and a "mask" is built by defining the voltage level and time difference between the minimum and maximum of the spike. To analyze a given spike, its shape is displayed on a storage scope through the mask corresponding to the spike potential preset in one channel of the spike discriminator. Values are set by potentiometers, and output is only obtained when the input signal fits the preset values within a predetermined tolerance. A delay line is added to allow analysis of the spike shape before the signal proceeds through the automatic discriminator system.

Results

One additional spike was clearly recognized and analyzed as a result of data reduction; the unit was determined to be a statoreceptor, of approximately the same size and characteristics as the one identified in initial data reduction. Results suggest that even units of the same nerve are independently affected by weightlessness, although the direction of the change is similar. Responses to the centrifuge spin cycle also followed the same variation pattern. Final conclusions reveal an increase in magnitude of fluctuation of impulse rate up to twenty times larger than on the ground, and a gradual return to normal by four to five days, with activity at rest producing about the same magnitudes as activity from ground controls. A change of gain and mode of responses to centrifuge spin cycles was observed. This apparently random change in the mode of operation of otolith cells from phasic to tonic and vice versa, involving both tonic and phasic statoreceptors, was still present after six days of weightlessness, contrary to the behavior of the spontaneous firing activity.

Title of Study

Orbiting Frog Otolith Experiment: Comparison to Control Studies

Science Discipline

Regulatory Physiology

Investigator	Institute
T. Gualtierotti	University of Milan

Co-Investigator(s)	Institute
Bracchi, F.	University of Milan
Morabito, A.	University of Milan
Esposti, D.	University of Milan
Crossignani, P.	University of Milan

Research Subject(s)

Rana catesbeiana (Bullfrog)

2 Demotorized Frogs (periodically centrifuged) Male

Ground-Based Controls

6 Stationary Controls (12 Frogs); 12 Centrifuge Controls (24 Frogs)

Key Flight Hardware

Frog Otolith Experiment Package (FOEP); FOEP Life Support System (LSS)

More Information

Mission p. 65-7; Publications p. 407; Hardware p. 490-93

Objectives/Hypothesis

The inflight results of the OFO-A experiment put forward several questions and problems, some of which could be answered by means of additional ground control studies. For example, a leakage of the O_2 supply had significantly increased the pressure inside the canister. Also there was a remote possibility that vibrations produced inflight by the water pump may have affected vestibular activity. The objective of this study was to essentially eliminate as many as possible variables other than weightlessness to explain the changes observed in orbit. Additional control experiments were performed on the ground with a much closer sampling time than used in the original flight controls.

Approach or Method

A variety of environmental variables were investigated using the FOEP module: temperature increase; hyperoxia/hypoxia; K^+, Na^+ and Ca^{++} variations in canister water; and natural decay (prolonged exposure), to assure that the responses observed were due to the microgravity component of space flight. The water circulation pump was suspended separately from the FOEP, connected by long polyethylene tubing, and package was mounted on a special anti-vibratory base. Vibrations were measured by a three-way accelerometer. In experiments at rest, samplings were recorded fifteen minutes every hour, and EKGs were recorded simultaneously, each time carefully maintaining the correct environmental variables (water temperature, water pressure, PO_2, etc.). In additional experiments, responses to centrifuge spin cycles were recorded for each hour for several days through computer operated automatic control.

Results

Vibrations were maintained below 10^{-3} in all directions. At rest the closer sampling confirmed the basic characteristic at rest with a range between one and four seconds, and 100% standard deviation with a coefficient of variation = 1 was confirmed. It was observed that occasionally the frequency of the discharge became heart rate dependent, although no explanation for this phenomenon could be found. It was thought that further experimentation with continuous recording for 48-72 hours was needed to understand vestibular activity at rest. The most intriguing effect of weightlessness was the changing of the vestibular statoreceptors mode from tonic to phasic and phasic to tonic; in all responses recorded from centrifuge spin cycles no change of mode was detected. Such control studies revealed that on the ground the response does not change in mode but in gain, as the decaying process continues. It was concluded that the periodical change of mode is a typical effect of weightlessness.

Title of Study

Chronobiology of Pocket Mice

Science Discipline

Regulatory Physiology

Investigator	Institute
R.G. Lindberg	University of California, Los Angeles

Co-Investigator(s)	Institute
Hayden, M.A.	University of California, Los Angeles

Research Subject(s)

Perognathus longimembris (Pocket Mouse)

6 Implanted Mice

Ground-Based Controls

6 Flight Backup;

Key Flight Hardware

Circadian Periodicity Experiment (CPE) Package: Pocket Mouse Experiment Hardware

More Information

Mission p. 79-81; Publications p. 407; Hardware p. 480-81

Objectives/Hypothesis

The objective of this experiment was to study the circadian system of a mammal during space flight. Specifically, it was intended to discover whether the periods of circadian rhythms of body temperature and animal movement of the pocket mouse would be affected under conditions of prolonged weightlessness. Free ranging mice were to be maintained in space in a closely controlled environment for 30-56 days under constant dark and constant temperature conditions. Pocket mice were chosen as subjects in part because of their ability to hoard food and survive without water. Their concentrated feces permit continuous isolation for several weeks uninterrupted by cage cleaning. Also the pocket mouse has a well defined marker of circadian phenomenon (torpor), in which its metabolic rate drops dramatically while at rest or in response to environmental stress. This is reflected as a drop in body temperature.

Approach or Method

Body temperature as a function of time is the primary data required from the mice, and a small block oscillator type transmitter was developed for the experiment. Subjects were selected on a number of criteria, including: expression of torpor, precision of circadian period of body temperature, body weight (10 grams) stability, food consumption, and general "housekeeping" behavior. Twenty-eight pocket mice were implanted with biotelemetry devices a little over a month before launch. Baseline data was collected at the lauch site in a specially designed holding unit, and flight and backup CPE packages were loaded with six animals each. Scientific analysis and evaluation of the experiment were derived from a master magnetic tape of all data retrieved from the CPE units and as necessary an examination of mission voice tapes. Average daily activity records referenced the time of arousal from torpor and were correlated with body temperature measurements.

Results

The quality of the data was excellent with data loss well below the specified 5% limit, and the flight hardware operated flawlessly for thirty hours after launch. Fairly regular bursts of activity at approximately sixty- to ninety-minute intervals were apparent in animals prior to launch and correlated with a rise in body temperature. Following launch, the tendency for bursts of activity persisted, but the pattern was more random. Analysis of activity data collected inflight demonstrated a good correlation with body temperature data, but the short inflight recording precluded any significant conclusions regarding patterns of activity. Attempts were made to average the daily activity record referenced to time of entry into torpor and other arbitrary phase markers, but the bursts of energy tended to average and meaningful patterns were not apparent. It was concluded that had the experiment been completed, the additional activity data would have been quite useful in accomplishing the stated objectives.

Title of Study
Circadian Rhythm in Vinegar Gnats

Science Discipline
Cell/Developmental Biology

Investigator
C.S. Pittendrigh

Institute
Stanford University

Co-Investigator(s)
none

Institute

Objectives/Hypothesis
This experiment was to investigate the circadian rhythm of the vinegar gnat Drosophila (Fruit Fly) by monitoring the eclosion (hatching) periodicity in the weightless environment.

Approach or Method
No information is available.

Research Subject(s)
Drosophila (Vinegar Gnat) Pupa

720 pupa (180 per Enclosure)

Ground-Based Controls
720 pupa Flight Backup

Key Flight Hardware
Circadian Periodicity Experiment [CPE] Package: Vinegar Gnat (Fruit Fly) Enclosure

More Information
Mission p. 79-81; Publications p. 407; Hardware p. 478-9

Results
No information is available.

Space Transportation System (STS) Program Experiments

Lists of experiments by discipline and reference number can be found in the mission profiles in Section 4, Programs, Missions and Payloads.

Title of Study

The Influence of Weightlessness on Lignification in Developing Plant Seedlings

Science Discipline

Plant Biology

Investigator	Institute
J.R. Cowles	University of Houston

Co-Investigator(s)	Institute
Scheld, H.W.	University of Houston
Lemay, R.	University of Houston
Peterson, C.	University of Houston

Research Subject(s)

Pinus elliotti Engelm (Pine Seedlings)

Vigna radiata (L.) Wilczek (Mung Bean), *Avena sativa* L. cv. (Oat)

Ground-Based Controls

Synchronous Mung Beans, Oat, and Pine Seedlings

Key Flight Hardware

Plant Growth Unit [PGU]

More Information

Mission p. 88-91; Publications p. 407; Hardware p. 506-7

Objectives/Hypothesis

Plants have evolved on Earth in a gravity environment, and higher plants have developed pathways to synthesize large amounts of the structural polymers, cellulose and lignin, in order to grow upright against the gravitational force. This study was designed to determine whether lignification occurs primarily as a response to gravitational forces, or whether it might be determined genetically, with only a minimum of environmental influences. Pine was chosen as the principal plant species for study because it is a gymnosperm with the capacity to synthesize large amounts of lignin.

Approach or Method

The experiment was carried out using six chambers in the Plant Growth Unit (PGU), which was placed in a locker in the orbiter mid-deck. The pine was germinated a few days in advance, to ensure that growth was underway before launch; oat and mung bean seeds germinated just hours before launch served as additional test specimens. The PGU was received at about 75 minutes after landing, and plants were observed, photographed and the atmospheric gases analyzed at the landing site. Pine seedlings from flight and control chambers were analyzed for lignin and protein content and for phenylalanine ammonia-lyase (PAL) and peroxidase activities. Selected mung bean and oat seedlings were also analyzed for lignin.

Results

The PGU functioned successfully with plant species chosen for the experiment, providing adequate nutrients and lighting for seed germination and seedling growth. Several mung bean seedlings experienced orientation difficulties in microgravity compared to controls, while germinating oat seeds did not exhibit any orientation problems in either environment. While the plants grew towards light as expected, almost half of the roots grew "upward" or towards the light as well; 25-40% of the mung bean and oat roots were growing upwards. Flight seedlings were shorter than the controls in all three species. CO_2 accumulation was species specific and similar in flight and control PGUs; mung beans had the greatest and pine the least. Overall lignin reduction in flight pine seeds over controls was 4-5% and not statistically significant. Flight mung beans showed a significant reduction in lignin content in comparison to controls, and PAL and peroxidase activities were reduced in flight pine seedlings. Results generally support the hypothesis that lignin synthesis is reduced in microgravity.

Title of Study
Karyological Observations in Developing Root Seedlings

Science Discipline
Plant Biology

Investigator	Institute
A.D. Krikorian	State University of New York

Co-Investigator(s)	Institute
O'Connor, S.A.	State University of New York
Cowles, J.R.	University of Houston
Scheld, H.W.	University of Houston

Research Subject(s)
Avena sativa (Oat Root Seedlings)
Vigna radiata (Mung Bean Root Seedlings)
18 Oat and 10 Mung Bean Root Seedlings

Ground-Based Controls
Synchronous Oat and Mung Bean Root Seedlings

Key Flight Hardware
Plant Growth Unit [PGU]

More Information
Mission p. 88-91; Publications p. 407-8; Hardware p. 506-7

Objectives/Hypothesis
Examination of plants grown under microgravity is still in its infancy. As more opportunities arise for making observations on space-grown material, it benefits investigators greatly to learn as much as possible, however fragmentary, from flight samples. As part of a larger investigation conducted in corporation with the HEFLEX experiment flown on both STS-2 and STS-3, this study sought to utilize oat and mung bean root seedlings germinated in space for karyological examinations.

Approach or Method
The experiment was carried out using the Plant Growth Unit (PGU), which was placed in a locker in the orbiter middeck. Mung beans and oats used in the experiment were germinated just hours before launch. Flight samples were made available a little over 3.5 hours after recovery, before sufficient time had passed for a cell division cycle to be completed prior to prefixation of the roots for chromosome analysis. Substantial effort was made to acquire data, and frequently as many as 10-20,000 cells were examined by actual count to find divisions.

Results
Overall length of the flight oat roots was some 6% less than in controls. Also, the number of roots growing upward was greater in flight samples (i.e. 24 out of 93 versus none of the 86 control seedlings). There were about one-tenth as many divisions as one would expect based on previous laboratory work with oat, and much chromosome fragmentation and breakage could be observed. Although based only on two plants, the number of divisions in the shoot growing region of flight oats was much greater than in the root tips, suggesting that root cells had been somewhat adversely affected by microgravity. In mung bean roots, the number of overall divisions was about half the number encountered in routine laboratory experimentation. No gross changes were detectable though, and except for a reduction in number of cells in division, mung bean roots were in good condition. Metaphase chromosomes from both mung bean and oat seedlings were generally more contracted and had a poorer spread than ground control material.

Title of Study
Cytological and Ultrastructural Studies on Root Tissues

Science Discipline
Plant Biology

Investigator	Institute
R.D. Slocum	Yale University

Co-Investigator(s)	Institute
Gaynor, J.J.	Rockefeller University
Galston, A.W.	Yale University
Krikorian, A.D.	State University of New York

Research Subject(s)
Avena sativa (Oat Root Seedlings)

Vigna radiata (Mung Bean Root Seedlings)

18 Oat and 10 Mung Bean Root Seedlings

Ground-Based Controls
Synchronous Oat and Mung Bean Root Seedlings

Key Flight Hardware
Plant Growth Unit (PGU)

More Information
Mission p. 88-91; Publications p. 408; Hardware p. 506-7

Objectives/Hypothesis
Root cap cells have been identified as the gravireceptive tissue in roots, and the directional sedimentation of root cap amyloplasts in response to gravity has been proposed as a possible mechanism of gravity-perception in these cells. This study was to investigate to what extent gravity, or its lack thereof, influences the organization of plant gravity-sensing tissues, such as the root cap.

Approach or Method
The experiment was carried out in the Plant Growth Unit (PGU), which was placed in a locker in the orbiter mid-deck. Mung beans and oats used in the experiment were germinated just hours before launch. Root tips were excised and immediately immersed in fixative following disassembly of the PGU. After transport from the landing site, samples were dehydrated, embedded, thin-sectioned, and stained appropriately for light and electron microscopy.

Results
Control and flight roots from oat seedlings exhibited characteristic monocotyledonous tissue organization and normal ultrastructural features, except for cortex cell mitochondria which exhibited a "swollen" morphology. The peripheral root cap cells were considerably more vacuolated in flight-grown plants, and various stages of cell division were observed in the meristemic tissues of oat roots. Mung bean roots also showed normal tissue organization, although the root cap cells in the flight samples were collapsed and degraded in appearance, especially at the cap periphery. At the ultrastructural level, these cells exhibited a loss of organelle integrity and a highly-condensed cytoplasm. This latter observation suggests a differing tissue sensitivity for the two species to growth conditions in space. The bases for abnormal root cap cell development is not understood, but the loss of these putative gravity-sensing cells holds potential significance for long term plant orientation during space flight.

Title of Study

Animal Studies on Spacelab-3

Science Discipline

Animal Maintenance

Investigator	Institute
P.X. Callahan	NASA-Ames Research Center

Co-Investigator(s)	Institute
Schatte, C.	NASA-Ames Research Center
Grindeland, R.	NASA-Ames Research Center
Funk, G.	MATSCO, Valley Forge
Lencki, W.	MATSCO, Valley Forge
Berry, W.	NASA-Ames Research Center
Tremor, J.	NASA-Ames Research Center
Fast, T.N.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

Saimiri sciureus (Bolivian Squirrel Monkey)

24 Flight Rats (4 BTS implanted); 2 Monkeys Male

Ground-Based Controls

24 Simulated Flight Control Rats (4 BTS implanted); 24 Preflight Control Rats; 2 Flight Simulation Control Monkeys

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module; RAHF Primate Cage Module; Biotelemetry System (BTS)

More Information

Mission p. 92-100; Publications p. 408-9; Hardware p. 466-7, 540-49

Objectives/Hypothesis

NASA-Ames undertook the first of several missions using animals as model mammalian systems with which to delineate the fundamental mechanisms of physiological response to an environment; i.e., microgravity. It was important to select an animal that grows normally, behaves normally, and is free from chronic stress to conduct high quality experiments on future missions. The primary objective of the Spacelab-3 mission was to evaluate the ability of the Research Animal Holding Facility (RAHF) to maintain animals in a normal, laboratory environment in space.

Approach or Method

Two monkeys and two groups of twelve rats each were flown in the primate and rodent cage modules of the RAHF, respectively. One group of rats was composed of twelve-week old adults and the other group was composed of juveniles about eight weeks old. Four of the large rats were implanted with a transmitter which permitted the continuous monitoring of heart rate and deep-body temperature. Food and water consumption, activity, and intermittent photographic records were obtained automatically and temperature, humidity, and light cycles were all controlled via the RAHF. Animals spent one hour in the Spacelab prior to launch, and rodents were not sacrificed until twelve hours following recovery. More extensive studies were preformed by various investigators on the rats, following biosample distribution.

Results

Data indicate that the RAHF was able to maintain both rats and monkeys in a relatively normal condition suitable for their use as experimental animals. Both monkeys ate less food and were less active in space than on the ground. One animal appeared to maintain a relatively normal eating behavior throughout the mission, while the other showed abnormally low food consumption for the first four days followed by substantial recovery during the last three days. Videotape recordings were consistent with the conclusion that the latter may have suffered from space motion sickness. Heart rate monitored in flight rats was lower at all times, and its circadian rhythm was unchanged from that of preflight. Mean body temperature was not changed; however, its rhythm was increased inflight, suggesting that microgravity may cause body-temperature rhythm to become free-running. With few exceptions all animals grew and behaved normally, were free of chronic stress, and differed from ground controls only in gravity dependent variables.

Title of Study

Rat Maintenance in the Research Animal Holding Facility During the Flight of Spacelab 3

Science Discipline

Animal Maintenance

Investigator	Institute
T.N. Fast	NASA-Ames Research Center

Co-Investigator(s)	Institute
Grindeland, R.	NASA-Ames Research Center
Kraft, L.	NASA-Ames Research Center
Ruder, M.	Santa Clara University
Vasques, M.	Santa Clara University
Lundgren, P.	NASA-Ames Research Center
Scibetta, S.	Santa Clara University
Tremor, J.	Santa Clara University
Buckendahl, P.	Santa Clara University
Keil, L.	NASA-Ames Research Center
Chee, O.	NASA-Ames Research Center
Reilly, T.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

24 Flight (4 BTS implanted) Male

Ground-Based Controls

24 Simulated Flight Control (4 BTS implanted); 24 Preflight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module; Biotelemetry System (BTS)

More Information

Mission p. 92-100; Publications p. 409; Hardware p. 466-7, 540-45, 548-9

Objectives/Hypothesis

The understanding of space biology and the biomedical problems of space requires that animals be carried into space and that the crew has access to them. In order to provide valid data on the biological effects of microgravity it is mandatory that the Research Animal Holding Facility (RAHF) adequately maintain the animals. This study was to evaluate the husbandry capabilities of the RAHF.

Approach or Method

A total of twelve large rats (400 g) and twelve small rats (200 g), all specific pathogen free, were flown in the RAHF for seven days. About three weeks before flight, biotelemetry transmitters for measurement of deep-body temperature and heart rate were implanted into seventeen large rats, five of which were selected for flight. Three to five days after surgery, implanted rats were placed in flight-type cages and the signals from their transmitters monitored to establish preflight diurnal rhythms. About thirteen days before launch, the remaining animals were also placed in flight-type cages where the rats could learn to use the flight feeders and lixits. Body, food and water weights were observed preflight. The 24 flight animals were inspected were inspected and weighed at recovery at the landing site in California then flown to Kennedy Space Center for further inspection, microbiological sampling, and sacrifice. Organs and tissues were weighed and preserved for biosample distribution for further analyses.

Results

The RAHF functioned well in providing an adequate environment and nutrition for the animals. When recovered, rats had an extensive coating of dried urine and food powder on their coats but were otherwise healthy and in good condition. A variable flow rate in the cage modules may have prevented some of the urine, feces and food powder from being deposited in the waste collection trays, which resulted in some of the particulate matter escaping from the RAHF during feeder and waste tray change-outs. Rats were strikingly calm when handled and did not resist oral swabs or fecal collection. An unexplained disparity was seen in the growth rates of flight rats with telemetry implants as compared to the implanted, ground controls. Elevated blood glucose concentrations in both large and small rats probably reflect re-entry stress, analogous to the responses shown by astronauts postflight. Other increased blood chemical responses shown by small flight rats included urea nitrogen, cholesterol, potassium and glutamic-pyruvic transaminase, and may indicate muscle wasting or responses of growing rats to micro-

Title of Study

Microgravity Changes in Heart Structure and Cyclic-AMP Metabolism

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
D.E. Philpott	NASA-Ames Research Center

Co-Investigator(s)	Institute
Fine, A.	National Institutes of Health
Kato, K.	NASA-Ames Research Center
Egnor, R.	National Institutes of Health
Cheng, L.	National Institutes of Health
Mednieks, M.	Northwestern University

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Modules; Biotelemetry System (BTS)

More Information

Mission p. 92-100; Publications p. 409-10; Hardware p. 466-7, 540-45, 548-9

Objectives/Hypothesis

Physiological changes which are the consequence of altered gravity conditions were studied in order to evaluate their effect on manned travel in space. Cardiac deconditioning has been found in astronauts, in humans after prolonged bed rest, in monkeys exposed to hypokinesia, and rodents exposed to increased gravity or weightlessness. Altered gravity has been shown to induce morphologically observable changes associated with myocardial degeneration (accumulation of lipid droplets, increased glycogen storage, alterations in microtubule distribution). In this experiment, cardiac ultrastructure and cyclic AMP metabolism were studied in tissues of space-flown rats.

Approach or Method

Tissues were post-fixed and processed for electron microscopy. Adenylate cyclase activities were monitored by following the conversion of ^{3}H-ATP to ^{3}H-cAMP, and cAMP was removed by column chromatography. Low Km and high Km cAMP-PDE activities were determined, and the reaction product (^{3}H-5 AMP) was elutriated from a polyacrylamide boronate affinity gel chromatographic column. cAMP-dependent protein kinase activity was measured as the incorporation y^{32}P-ATP into protein. Assays were carried out with protamine as the exogenous phosphoacceptor protein and in either the absence or presence of exogenous (10^{-6}M) cAMP, as was phosphorylation of endogenous substrate proteins without the addition of protamine. Compartmental subunits distribution of regulatory cA-PK subunits was determined using a photoaffinity labeling method with [^{32}P]-8-azido cyclic AMP, and type I and type II cA-PK were separated on SDS-gradient gels and identified by autoradiography of Western blots.

Results

Changes in ultrastructure and biochemistry were found in the heart tissue of flown rats. An accumulation of lipid droplets and changes in glycogen deposits and microtubules were observed at the electron microscope level as a result of space flight. Adenylate cyclase and low Km PDE activities were not altered, but a decrease in high Km phosphodiesterase was seen in flight homogenates. Protein kinase activity decreased, while activity ratios increased, indicating that the holoenzyme was more extensively dissociated and inactivated during space flight. Together with other studies of responses to catecholamines, results show that ß-adrenergic responses were affected during space flight. While events at the cell surface level were within the range of homeostatic control, intracellular signal processing of the receptor interactions was modified. Results suggest that heart muscle energy metabolism may be altered in microgravity.

Title of Study

Atriopeptin in Atria and Plasma of Rats Orbited Aboard NASA Spacelab-3 for Seven Days

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
W. Inge	Emory University School of Medicine

Co-Investigator(s)	Institute
Hartle, D.	Emory University School of Medicine

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control; 16 Laboratory Control (anesthesia control)

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 409-10; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Atriopeptins are of interest in space flight due to their putative involvement in the adjustment of astronauts to the cephalad shift of body fluid experienced in orbital flight. This shift of some two liters of fluid is thought to stimulate right atrial stretch receptors, resulting in the release of atriopeptins which cause natriuresis and diuresis by direct action on the kidney, inhibition of aldosterone and vasopressin secretion, and by dilation of large vessels which further enhances central pooling of blood. In this study, atriopeptin (AP-3) was examined in the atria and plasma of space-flown rats.

Approach or Method

Right and left atria were dissected separately and about 40 mg of tissue from the ventricular apex was removed. A plasma sample was also taken. After transport, samples were analyzed for atriopeptin immunoreactivity (APir) by radioimmunoassay. To determine if the halothane anesthesia or decapitation might have altered APir, a group of sixteen rats equipped with chronic catheters in their left carotid artery were also studied. Half of the rats were anesthetized with halothane, and a blood sample was taken from the catheter of all rats before sacrifice. Laboratory catheter and trunk samples were then similarly analyzed for APir.

Results

While the flight animals' right and left atria had higher levels of AP-3 than the synchronous controls, the difference was not statistically significant. Due to the high level of uncontrolled stresses on both groups of rats, the observed values cannot be considered representative of basal AP-3 levels in the rat. The laboratory study demonstrated the profound effect of the halothane anesthesia on AP-3. Plasma AP-3 levels of rats anesthetized were over 400% higher than in conscious controls. It is evident that the large number of stresses connected with transporting and handling animals for space flight make it essential that studies of labile factors such as atriopeptins be conducted on samples obtained inflight, rather than attempting to rely solely on postflight sampling.

Title of Study

Effect of Flight on Mission SL-3 on Cytokine Production By Rats

Science Discipline

Immunology/Microbiology

Investigator	Institute
C.L. Gould	NASA-Ames Research Center

Co-Investigator(s)	Institute
Williams, J.A.	NASA-Ames Research Center
Gould, C. L.	University of Louisville
Lyte, M.	University of Pittsburgh
Sonnenfeld, G.	University of Louisville

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

10 Flight Male

Ground-Based Controls

10 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Modules

More Information

Mission p. 92-100; Publications p. 410; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Several lines of evidence suggest that there may be compromises of immune responses in humans or experimental animals exposed to weightless conditions during space flight, or maintained in hypodynamic, hypokinetic, antiorthostatic models simulating some aspects of weightlessness. Among those immune responses and defenses possibly altered in such conditions is the cytokine system. The present study was carried out to determine the effects of a period of weightlessness on interferon (IFN) and interleukin-3 (IL-3) production by rats.

Approach or Method

Spleens were removed from rats, separated into individual cells, suspended, and supplemented with antibiotics. Cultures were then stimulated with concanavalin A for 48 hours to induce IFN-gamma and IL-3. Supernatant fluids were harvested from the culture. Supernatant fluids were analyzed for IFN antiviral activity. Due to cross reaction of rat and mouse IFN, the assay was carried out on mouse L-929 cells using the Indiana strain of vesicular somatitis virus as the target. Assays used were either a plaque reduction or microplaque reduction, and the IFN titer corresponded to the reciprocal of the greatest dilution of the test sample that reduced virus plaques by 50%. IL-3 assays were carried out by determining the ability of the supernatants to support the growth of an IL-3-dependent cell line.

Results

Spleens of all flown rats were substantially reduced in weight compared to controls. Spleen cells of seven of ten ground control rats produced moderate levels of IFN-γ, while only one of ten flight rats whose IFN-γ production was analyzed produced any IFN-γ, and the level of production of that one rat was at the lower level of detection of the assay system. Decreased spleens size in flown rats may be due to altered activity of T-lymphocytes in the spleen which are responsible for IFN-y production. The drop in IFN-γ production could been related to microgravity, or to stress during postflight transport. However, it is unknown if the IFN-γ production decrease is permanent or transient in nature (i.e., would IFN-γ production have returned to normal had the rats been allowed to recover further on the ground before sacrifice). Studies with antiorthostatic modeling have suggested that, in mice, ability to produce IFN recovers after return to normal caging. IL-3 production was not affected by space flight. Thus space flight only affects specific components of the immune response.

Title of Study

The Influence of Space Flight on the Rat Soleus

Science Discipline

Musculoskeletal

Investigator	Institute
V.R. Edgerton	University of California, Los Angeles

Co-Investigator(s)	Institute
Martin, T.P.	University of California, Los Angeles
Grindeland, R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Flight Simulated

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 410-11; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Results from previous Cosmos experiments have shown that several biochemical and physiological properties of rat skeletal muscle are altered after space flight. These studies have been based primarily on analysis of whole muscle properties. Since there is a potential difference in the response of muscle fibers differing in size and alkaline adenosinetriphosphatase (ATPase) type, this study focused on the adaptation to space flight of single muscle fibers. The purposes of the study were: 1) to define the size and metabolic responses to space flight and 2) to determine the specificity of these responses to the muscle and the ATPase type and size of its fibers.

Approach or Method

The left soleus (SOL), adductor longus (AL), plantaris (PL), extensor digitorum longus (EDL), and medial gastrocnemius (MG) muscles were removed. Frozen serial sections (10 µm) were prepared for determination of alkaline (pH 8.8) myofibrillar ATPase staining density, and SDH and GPD activity. Fiber cross-sectional areas were also determined from ATPase stained sections. A computer-assisted image analysis system was used to quantify the rate of change of optical density (OD) for each fiber, and the rate of staining (OD/min) was directly proportional to the enzyme activity. Remaining SOL and EDL tissue was powdered and lypholized for biochemistry. Myofibrillar ATPase, the release of inorganic phosphate in the reaction, and protein content were determined from 1 mg samples.

Results

Wet weight of each of the flight muscles was significantly reduced compared to controls; loss varied from 36% in the SOL to 15% in the EDL. Cross-sectional areas of fibers in flight muscles were also reduced, except for the dark ATPase in the MG. The greatest relative fiber atrophy occurred in the muscles with the highest proportion of light ATPase fibers. An increase in the percentage of dark ATPase fibers was also observed in flight muscles with a predominance of light ATPase fibers. There was an increase in the biochemically determined myofibrillar ATPase activity of tissue sections of the flight SOL. No changes in histochemical or biochemical measures of ATPase activity were observed in the EDL. In general, the SDH activity of the flight muscles was maintained, whereas GPD activity either was maintained or increased. This suggests an increase in the proportion of fast oxidative-glycolytic fibers in some muscles, apparently at the expense of slow oxidative fibers.

Title of Study

Electron Microprobe Analyses of Calcium, Sulfate, Magnesium, and Phosphorous Distribution in Incisors of Spacelab-3 Rats

Science Discipline

Musculoskeletal

Investigator	Institute
G.D. Rosenberg	Indiana/Purdue University

Co-Investigator(s)	Institute
Simmons, D.J.	Washington University, St. Louis

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

Flight Number Unknown Male

Ground-Based Controls

Simulated Flight Number Unknown

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 411; Hardware p. 540-45, 548-9

Objectives/Hypothesis

This experiment was to determine if the microgravity of space flight altered the normal patterns of mineralization during amelogenesis and dentinogenesis in the rat incisor, a tissue which preserves a thirty-day record of growth in its concentric growth increments. Ca, S, Mg, and P distributions were determined to assess mineralization patterns.

Approach or Method

The distribution of Ca, S, Mg, and P was mapped within the incisors using an electron microprobe. Medial sections of incisors from Spacelab-3 rats and ground-based controls were analyzed with the electron microscope. Traverses were Fourier analyzed and frequency smoothed by recombining 50% of the harmonics. Calcium ratios were determined. Results were compared with ground-based controls and incisor studies conducted on other space-flown rodents.

Results

Newly-formed incisor dentin from SL-3 flight rats contained higher than normal concentrations of calcium, and lower than normal magnesium concentrations. Though mean tissue Ca/P ratios in flight rats were normal, detailed analysis indicates that the Ca/P ratios tend to be lower than normal in the most recently formed dentin of the flight rats. Ca/Mg ratios were statistically different in the flight rats. Ca/S ratios were highest in flight rats by virtue of higher tissue Ca. Though not as pronounced, these results are consistent with Cosmos 1129, where large sulfur-"spikes" were observed in the rat dentin, apparently a result of the longer duration (18.5 days) of that flight. Results further suggest that continuously growing rat incisors provide useful records of the effects of weightlessness on Ca metabolism. The failure of flight rat dentin to exhibit the normal decrease in Ca^{++} within about 100µm of the pulp cavity could indicate that dentinogenesis was slowed during the mission, allowing time for the secondary mineralization/apatite crystal growth to increase the local Ca/P and Ca/Mg ratio.

Title of Study

Microprobe Analyses of Epiphyseal Plates from Spacelab 3 Rats

Science Discipline

Musculoskeletal

Investigator	Institute
P.J. Duke	University of Texas Dental Branch

Co-Investigator(s)	Institute
Janer, L.	University of Texas Dental Branch
Campbell, M.	University of Texas Dental Branch
Montufar-Solis, D.	University of Texas Dental Branch

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 411-2; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Ultrastructural studies of epiphyseal plates from young rats flown aboard Cosmos 1129 showed that production and mineralization of matrix vesicles were delayed in flight rats. Also, the matrix of metaphyseal trabeculae contained fewer collagen fibers than did the matrix of ground controls, and the collagen was less mature as shown by smaller fiber size and lack of banding. A comprehensive analysis of plate and zone height was not carried out but no apparent difference was seen in height of zones or numbers of cells per zone. This study was to determine if differences in bone matrix formation could be observed after seven days in microgravity.

Approach or Method

Proximal tibial epiphyseal plates were dissected from right tibias of six flight and six control rats and prepared for microprobe analysis using a freeze substitution method. Measurements of matrix composition were made in longitudinal septi of each of the four zones: resting, proliferative, hypertrophic, and calcifying. Na, Mg, P, Ca, and K distributions were among the parameters measured. Portions of these plates were also analyzed extensively by light and electron microscopy to detect differences in height and cell number per plate and zone, as well as ultrastructure of collagens, proteoglycan granule size and number per area, and matrix vesicle distribution.

Results

In control plates, all zones had high levels of Na, and in unmineralized regions, low levels of Mg, P, and Ca. K and S levels were high and increased from the proliferative to the calcifying zones. The level of P rose in the mineralized regions of the matrix and Ca/P ratios ranged from 1.2-1.4. In contrast, flight animals had very low Na and K values; Mg levels were unaffected. S levels were less than half of control values, and Ca values were less in both unmineralized and mineralized regions, although the Ca/P ratio was similar to that of controls. These data indicate that even a short space flight can alter bone mineralization, and that the primary defect is at the level of initial matrix production. Data is consistent with other flight studies, and in contrast to the increased matrix formation seen in studies of embryonic limbs centrifuged *in vitro*. Less matrix formation is also consistent with analyses of growth plate height and the hypothesis that decreased gravity causes decreased differentiation.

Title of Study

Effect of Seven Days of Spaceflight on Hindlimb Muscle Protein, RNA and DNA in Adult Rats

Science Discipline

Musculoskeletal

Investigator	Institute
J. Steffen	University of Louisville

Co-Investigator(s)	Institute
Musacchia, X.J.	University of Louisville

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

Flight Number Unknown — Male

Ground-Based Controls

Simulated Flight Control Number Unknown

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 412; Hardware p. 540-45, 548-9

Objectives/Hypothesis

In rats, muscles composed predominantly of slow-twitch fibers (soleus) are most responsive to the unloading associated with weightlessness, whereas those composed of fast-twitch fibers (EDL) display reduced sensitivity. Muscle atrophy resulting from whole body suspension has been associated with reduced protein content, elevated DNA concentration, and decreased RNA content. The aim of the present study was to investigate these same parameters (protein, DNA, RNA) in hindlimb muscles of rats exposed to seven days of weightlessness.

Approach or Method

Soleus, gastrocnemius and EDL muscles were excised from flight and control subjects, frozen in liquid nitrogen, and shipped to the lab on dry ice where they were stored at -80 °C until analyzed. Protein content was quantified with a modified Lowry technique; DNA was determined calorimetrically with diphenylamine; and RNA was assayed spectrophotometrically at 260 nm. A second piece of muscle was utilized to fractionate sarcoplasmic and myofibrillar proteins with consecutive extractions of tissue homogenates with low and high salt solutions.

Results

In flight and control animals, total protein contents were reduced in parallel with muscle weights. The proportion of total noncollagenous proteins increased significantly in the soleus muscles of the flight rats, suggesting a more pronounced effect on myofibrillar proteins than on sarcoplasmic proteins. There were no significant changes in absolute DNA contents, but a significant increase in DNA concentration in soleus muscles from flight rats. Coupled with observations of decreased protein content, this suggests a reduction in the volume of fibers in the soleus rather than a loss of cells as the factor in the reduced muscle mass. Absolute RNA contents were significantly decreased in the soleus and gastrocnemius muscles of flight rats, with RNA concentrations reduced 15-30%. These results agree with previous ground-based observations on the suspended rat with unloaded hindlimbs and support continued use of this model.

Title of Study
Morphologic and Histochemical Studies of Bone Cells from SL-3 Rats

Science Discipline
Musculoskeletal

Investigator
S.B. Doty

Institute
Columbia University

Co-Investigator(s)
none

Institute

Research Subject(s)
Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls
6 Simulated Flight Control

Key Flight Hardware
Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information
Mission p. 92-100; Publications p. 412-3; Hardware p. 540-45, 548-9

Objectives/Hypothesis
Non-weight bearing or hypogravity conditions are known to result in skeletal loss in the long bones. The mechanism is unknown but one hypothesis suggests that the lack of mechanical force or stress on the bone results in reduced osteoblastic activity and thus reduced new bone formation. The objectives here were to investigate the cellular activity of the bone forming cells, the osteoblast, in animals exposed to seven days of microgravity.

Approach or Method
The osteoblasts from tibias of adult flight and control rats were studied using cytochemical methods for alkaline phosphatase, acid phosphatase, and dipeptidyl peptidase II. In addition, electron microscopy was used in combination with morphometric techniques to measure numbers of secretory granules containing procollagen, to count lysosomes and to measure cytoplasmic areas of osteoblasts.

Results
Measurements of alkaline and acid phosphatase, Golgi activity, secretory granule size, and lysosomal activity, all indicated very little difference between flight and flight-simulated controls. However, there was a tendency for osteoblasts in compact bone of flight animals to show a smaller cytoplasmic volume compared to non-flight controls. Thus the "processing" of protein (including procollagen) in these osteoblasts, especially the dipeptidase cleavage activity, may be operating normally but within a smaller cytoplasmic volume, and this normal proteolytic activity within a smaller volume could result in more rapid intracellular protein degradation, including procollagen, and thus less collagen secretion. This, in effect would result in less new bone formation. An alternative explanation concerns the twelve-hour postflight delay before animal sacrifice. As collagen synthesis is stimulated during cell growth, the osteoblasts could have begun to return to normal function in this period. With a longer recovery time one presumes that a return to normal cell size would also have occurred.

Title of Study

Osteocalcin as an Indicator of Bone Metabolism During Spaceflight

Science Discipline

Musculoskeletal

Investigator	Institute
P. Patterson-Buckendahl	University of California, San Francisco

Co-Investigator(s)	Institute
Grindeland, R.	NASA-Ames Research Center
Martin, R.	University of California, Davis
Cann, C.	University of California, San Francisco
Arnaud, S.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

12 Flight Male

Ground-Based Controls

12 Simulated Flight Control; 12 Preflight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 413; Hardware p. 540-45, 548-9

Objectives/Hypothesis

The early changes in bone metabolism that precede the documented decrease in bone formation witnessed in previous Cosmos flights are not understood. A primary defect in osteoblast rather that osteoclast function is suggested by bone histomorphometry measurements and kinetic studies with stable calcium isotopes in young animals. Osteocalcin, a noncollagenous bone protein synthesized by the osteoblast, has been suggested as a good biochemical marker for bone turnover or bone formation. This study was to determine if microgravity affects either the bone content or circulating levels of osteocalcin.

Approach or Method

Blood was obtained from all animals at sacrifice and analyzed for Ca, P, total protein, and alkaline phosphatase. The humeri from flight and control rats were tested for breaking strength in three-point bending using an Instron materials testing machine. The load was applied to the medial surface at midshaft halfway between the outer supports, which were 17 mm apart beneath the posterior aspect of the bone. The deformation rate was 1 mm per minute; load deformation curves were analyzed for ultimate load and deformation, work to ultimate load, and initial stiffness. Third lumbar vertebrae were ground to a fine powder in a liquid nitrogen mill, and osteocalcin was extracted from 1 mg portions of bone powder. Because bone and serum osteocalcin in rats are age dependent, flight values were compared to both actual and estimated control values in order to compensate for the age difference between the two groups of rats.

Results

Vertebral osteocalcin content was decreased in flight animal relative to controls, as were humeral breaking strength and serum osteocalcin levels, even after adjustment for age-related changes. The bone osteocalcin decrement was greater than the decrement in bone mass, indicating that osteocalcin per unit bone mass was reduced. The normal inverse relationship between serum and bone osteocalcin was disrupted in the flight rats, whose serum content was much lower. If the source of serum osteocalcin is new synthesis by the bone cells, then these decreased levels are likely to represent decreased osteoblast activity associated with reduced skeletal growth during space flight. Although a dose dependent steroid induced decrease in serum osteocalcin has been reported, this does not appear to be a factor here since serum corticosterone was the same in all groups and unrelated to serum osteocalcin. While the function of osteocalcin may not yet be known, it appears to be a most sensitive indicator of the early effects of space flight on metabolism.

Title of Study

Responses of Amino Acids in Hindlimb Muscles to Recovery from Hypogravity and Unloading by Tail-Cast Suspension

Science Discipline

Musculoskeletal

Investigator	Institute
M.E. Tischler	University of Arizona

Co-Investigator(s)	Institute
Henriksen, E.	University of Arizona
Jacob, S.	University of Arizona
Cook, P.	University of Arizona

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control; 10 Tail-Suspended; 10 Tail-Suspended with 12 Hours Loading (sacrifice delay control)

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 413; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Previous work has shown that certain amino acids undergo marked changes in the soleus muscle in response to unloading by tail-cast hindlimb suspension. In light of the many changes in muscle amino acids in response to decreased use through unloading, it seemed important to make similar measurements in muscles subjected to unloading by hypogravity. The effect of microgravity on the amino acid response in muscle tissue in rats was investigated and the use of the suspension model as a substitute for hypogravity was evaluated.

Approach or Method

Amino acids were assayed in muscles from rats exposed to seven days of hypogravity (space flight) and twelve hours of gravity or six days of suspension with or without twelve hours of loading. Soleus muscles were weighed and slices homogenized in cold perchloric acid (15-20 mg muscle/ml acid). After centrifugation to remove the protein precipitate, the supernatant solution was removed and neutralized to pH 6.5-7.5. Fluorometric analysis of glutamine, glutamate, aspartate, and malate were completed within three days of sample preparation.

Results

Despite the twelve hours of exposure to normal gravity following the seven days in space, amino acids in muscles of SL-3 rats showed some similarities to those of suspended rats. Since aspartate recovered in unloaded soleus but apparently not in soleus of flown rats, it is conceivable that the additional stress to these animals of landing and transcontinental flight, may have preserved their catabolic state to some extent. However, the ability to synthesize glutamine (i.e., ammonia is produced) may have returned to near normal while the capacity to synthesize glutamine is clearly increased presumably due to glucocorticoid (i.e., response to stress) effects on synthetase. Although it is unfortunate that the flight animals were not sacrificed immediately postflight, the data do support the possibility that the suspension model may mimic the effects of weightlessness.

Title of Study

Muscle Protein and Glycogen Responses to Recovery from Hypogravity and Unloading by Tail-Cast Suspension

Science Discipline

Musculoskeletal

Investigator	Institute
E.J. Henriksen	University of Arizona

Co-Investigator(s)	Institute
Tischler, M.	University of Arizona
Jacob, S.	University of Arizona
Cook, P.	University of Arizona

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control; 10 Tail-Suspended; 10 Tail-Suspended with 12 Hours Loading (sacrifice delay control)

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 413-4; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Previous studies in this lab using the tail-cast hindlimb suspension model have shown that there are specific changes in protein and carbohydrate metabolism in the soleus muscle as a response to unloading. Also, fresh tissue tyrosine and its *in vitro* release from the muscle are increased in the unloaded soleus, indicating that this condition causes a more negative protein balance. This study was to investigate the effect of microgravity and suspension on protein and carbohydrate metabolism in a number of rat hindlimb muscles.

Approach or Method

Amino acids were assayed in muscles from rats exposed to seven days of microgravity and twelve hours of gravity immediately postflight, and rats exposed six days of suspension with and without twelve hours of loading. Overall changes in body weight, and changes in mass, protein, tyrosine, and glycogen in the hindlimb muscles were compared in SL-3 and ground control rats. Sliced muscles were placed in KOH for glycogen determination or cold perchloric acid for homogenization. Glucose was assayed enzymatically. Homogenates were then separated by centrifuge; protein was assayed spectrophotometrically; and the supernatant was analyzed fluorometrically for tyrosine and other amino acids.

Results

Flight and ground control rats grew similarly, while unloaded suspension rats grew slower than loaded suspension rats. In flight, unloaded and loaded suspension rats, the soleus atrophied and the gastrocnemius, plantaris and extensor digitorum longus showed reduced growth. The tibialis anterior showed little response. Changes in mass and protein content correlated in these muscles. Muscles from the flight animals showed dramatic increases in glycogen, the soleus being most responsive. Tail-suspension rats without loading showed a greater glycogen concentration in the soleus only, with an even greater value in the loaded, tail-suspension soleus. Only in flight soleus was tyrosine greater than the control, suggesting a more negative muscle protein balance. In this study, recovery from suspension decreased soleus tyrosine. These results suggest that the additional stress placed on the flight rats postflight by additional transport may have prevented the soleus from showing evidence of recovery from microgravity.

Title of Study

Morphological and Biochemical Changes in Soleus and Extensor Digitorum Longus Muscles of Rats Orbited in Spacelab 3

Science Discipline

Musculoskeletal

Investigator	Institute
D.A. Riley	Medical College of Wisconsin

Co-Investigator(s)	Institute
Ellis, S.	NASA-Ames Research Center
Slocum, G.R.	Medical College of Wisconsin

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

12 Flight Male

Ground-Based Controls

12 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 414; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Progressive skeletal muscle weakness plagues astronauts and cosmonauts during long duration space missions. Non-invasive studies suggest simple muscle cell shrinkage because preflight levels of strength were regained. Muscle cell loss can be masked by compensatory hypertrophy of the surviving cells. Invasive studies are required to assess the mechanism of muscle atrophy. This study was to investigate muscle wasting in space-flown rats.

Approach or Method

Hindlimb muscles were harvested from flight and similarly caged control rats 12-16 hours postflight. Histochemical analysis was performed using established laboratory techniques. Fiber area, density, size, and type were examined in extensor digitorum longus (EDL) and soleus muscles. Tissues embedded in Epon were thin sectioned and examined with an electron microscope. Mitochondrial area % and focal areas of myofibril disruption were quantified using a computer digitizing planimetry.

Results

Mean soleus fiber area decreased 29% while EDL fibers atrophied 23%. Most atrophic fibers appeared to exhibit simple cell shrinkage but up to 1% of the fibers in flight soleus muscles appeared to undergo cell death. Also present were large round fragmented fibers possibly broken down during the postflight exposure to terrestrial gravity (twelve hours) or during tissue processing. Both the EDL and soleus muscles acquired fast histochemical properties. Following flight, tripeptidylaminopeptidase and total calcium activated protease (CAP) activities were significantly increased by 60% and 26%, respectively; these two proteases may function in myofibril breakdown. Elevation of CAP suggests that myofilaments are attacked by soluble neutral proteases which gain access to the edges and interiors of myofibrils. The present observations indicate that focal degradation of myofibrils is the key process of myofibril breakdown.

Title of Study

Bone Maturation in Rats Flown on the Spacelab-3 Mission

Science Discipline

Musculoskeletal

Investigator	Institute
J.E. Russell	Washington University School of Medicine

Co-Investigator(s)	Institute
Simmons, D.J.	Washington University

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 414; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Work on the non-weight bearing mandibles of rats flown in the Cosmos 1129 mission showed that there was a gravity component to skeletal maturation. The alterations seen in total calcium, phosphorus and matrix hydroxyproline suggest that microgravity interferes with the formation of the collagen fiber cross linkages which provide nucleation sites for bone apatite nucleation and crystal growth. This study was to determine whether altered matrix-mineral maturational patterns during space flight are also found in elements of the weight bearing skeleton.

Approach or Method

Femurs from six flight and six control rats were obtained following flight and fixed in ethyl alcohol. The specimens were split and the tissue dissected into trabecular and cortical bone samples. 40 µm particles were separated by gradient separation into four specific gravity fractions. The Ca, inorganic phosphorus, and collagen hydroxyproline contents of each obtained fraction were determined by techniques used previously in related research on rats.

Results

Total femoral calcium concentrations in trabecular and cortical regions were normal for the flight animals. However, the two groups could be distinguished by the distributional patterns of calcium within the specific-gravity fractions indicating that flight femurs are relatively more "mature" than bones from control rats, perhaps due to a space flight associated decrease in bone turnover. The data also demonstrate that there are significant differences in the maturational patterns of mineral and matrix moieties. Thus, in the cortical bone, the matrix/mineral shifts were better defined in the lower density fractions. Despite the differences, the trends all suggest an impairment of bone growth and a relative increase in skeletal maturation. While the shift in the distributions of the matrix and mineral moieties was not as pronounced as they were in the longer Cosmos 1129 mission, data indicate that changes in skeletal biochemistry/histomorphometry begin during the first seven days of space flight.

Title of Study

Space Lab 3: Histomorphometric Analysis of the Rat Skeleton

Science Discipline

Musculoskeletal

Investigator	Institute
T.J. Wronski	University of Florida

Co-Investigator(s)	Institute
Morey-Holton, E.	NASA-Ames Research Center
Maese, A.	NASA-Ames Research Center
Walsh, C.	University of Florida

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

11 Flight Male

Ground-Based Controls

11 Flight Simulated

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 415; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Decreased bone formation is a potentially serious consequence of space flight. Skylab astronauts exhibited a 4% decline in the bone mineral density of the calcaneus after 84 days of orbital flight. Rats orbited on Cosmos biosatellites were also characterized by loss of trabecular bone mass and decreased breaking strength of the lumbar vertebra and femur. This study was to investigate the physiologic effects of weightlessness on the rat skeleton, after seven-days of orbital flight aboard the Space Shuttle.

Approach or Method

To label bone formation sites, calcein was administered to the large rats (384± 9.3 g at launch) nine and two days preflight, at a dose of 10 mg/kg body wt. At recovery an eleven- to seventeen-hour delay occurred before rats were euthanized. The right tibial shaft, right proximal humerus, and fourth lumbar vertebral body were removed. Tibial cross-sections were mounted and examined using an interactive image analysis system, which allowed periosteal perimeter and area measurements to be calculated from traces of concentric surfaces of calcein labels. Measurements in the humerus and vertebra included trabecular bone volume (%), osteoclast surface (%), osteoblast surface (%), numbers of osteoclasts and osteoblasts, and rate of longitudinal bone growth. In small rats (196±5 gm at launch), the fourth lumbar vertebra was processed as it was for large rats, the right proximal tibia was decalcified, embedded and sectioned longitudinally. The perimeter of individual osteoblasts was measured in micrographs of the primary spongiosa.

Results

Trabecular bone mass was not altered during one week of weightlessness. Strong trends were observed in flight rats for decreased periosteal bone formation in the tibial diaphysis, reduced osteoblast size in the proximal tibia, and decreased osteoblast surface and number in the lumbar vertebra. Vertebral osteoblastic parameters were reduced by 50% in the large flight rats while the same parameters were relatively unchanged in small rats, a finding which may be explained by the greater number of osteoblast precursors in rapidly growing small rats which allowed a faster skeletal recovery during the eleven- to seventeen-hour postflight delay. For the most part, results indicate that seven days of weightlessness are not sufficient to induce histologically detectable loss of trabecular bone in rats. However, large flight rat exhibited strong trends for an inhibition of cortical and trabecular bone formation, which are consistent with the hypothesis that the primary skeletal alteration induced by space flight in growing rats is decreased bone formation.

Title of Study

Census of Osteoblast Precursor Cells in Periodontal Ligament (PDL) of Spacelab-3 Rats

Science Discipline

Musculoskeletal

Investigator	Institute
W.E. Roberts	University of the Pacific

Co-Investigator(s)	Institute
Fielder, P.J.	University of the Pacific
Rosenner, L.M.L.	University of the Pacific
Maese, A.C.	University of the Pacific
Gonslaves, M.R.	University of the Pacific

Research Subject(s)

Rattus norvegicus (Sprague-Dawley Rat)

10 Flight Male

Ground-Based Controls

10 Flight Simulated

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 415; Hardware p. 540-45, 548-9

Objectives/Hypothesis

This experiment was to examine space flight effects in the non-weightbearing bone of the rat periodontal ligament. The objective is to determine the relative influence of weightlessness on cell census of an osteogenic tissue. Previous flight data have documented a compromise in preosteoblasts, but the present was the first opportunity to evaluate postflight recovery of osteoblast differentiation.

Approach or Method

The right mandible, ulna/radius, both sides of the maxilla, and last two thoractic and first lumbar vertebrae were recovered from large (350 g at launch) and small (200 g at launch) space-flown rats and comparable controls. Large rats were perfused *in situ* while bones and teeth of the smalll animals were fixed by immersion in neutral buffered formalin. Maxillary halves were demineralized; specimens were divided with a razor blade along the midsegittal plane of the mesial root of the first molar; and the medial surface was embedded. First molars and surrounding periodontium were serially sectioned at 3 µm and stained. Nuclear length and width were measured at 1,000x with an ocular micrometer. Nuclear volume was calculated and fibroblastlike cells were classified: A+A' (40-79); B (80-119); C (120-169); and D (170 μm^3).

Results

Since the histogenesis sequence is A→A'→C→D→osteoblast, the relative incidence of A+A' to C+D cells is an osteogenic index. An insignifcant difference in A+A' or C+D cells may reflect partial recovery of preosteoblast formulation (A→C) during the twelve-hour postflight period. Large flight rats, however, demonstrated increased numbers of A+A', indicating an inhibition of preosteoblast formation (A→C). Hence, at least with older rats, a seven-day flight is adequate to reduce PDL osteogenic potential, suggesting an inhibition in PDL osteoblast differentiation and/or specific attrition of C+D cells, that does not recover by twelve hours postflight. As circadian rhythmicity is important to the mechanism of osteoblast histogenesis, disruption of the circadian timekeeping system in SL-3 rats may have also interfered with normal osteoblast production. The effect of short-duration space flight on relative numbers of osteogenic cells may be a composite response to multiple factors, including unloading, fluid shifts and altered circadian rhythm.

Title of Study

Changes in Functional Metabolism in the Rat Central Nervous System Following Spaceflight

Science Discipline

Neuroscience

Investigator	Institute
D. Murakami	University of California, Davis

Co-Investigator(s)	Institute
Miller, J.	University of California, Davis
Fuller, C.	University of California, Davis

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

5 Flight Male

Ground-Based Controls

5 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 415; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Many physiological systems are affected by the microgravity conditions of space flight. Since these systems are directly or indirectly regulated by the nervous system, it is important to know how central control mechanisms are affected by weightlessness. This study was to examine the changes in the pattern of metabolic activity in the brains of rats following space flight.

Approach or Method

Alternate coronal sections (40 µm) through the hypothalamus were cut on a freezing microtome. One series of sections was stained with thionin and the alternate series with cytochrome oxidase techniques to reveal the pattern and intensity of metabolic activity. The neuronal metabolism of the paraventricular nucleus (PVN) and supraoptic nucleus (SON) was quantified by taking the percent difference between the densitometer measurements of the particular nucleus and the surrounding hypothalamus.

Results

Cytochrome oxidase activity and soma size within the PVN of flight rats varied considerably depending on each rat's drinking activity. Rats that demonstrated normal drinking patterns exhibited decreases in neuronal metabolism within the PVN relative to controls. Mild dehydration increased neuronal metabolism within the PVN to levels equal to that of controls; greater dehydration caused a further increase in metabolism and also an increase in soma size of neurons. Preliminary examination of other hypothalamic and motor system nuclei did not reveal obvious changes in metabolic activity. If the flight rats were in a dynamic state of body fluid redistribution, it would be important to determine whether neuronal metabolism within the PVN and SON returns to that of ground controls once a steady state is achieved. On the other hand, if the observed decrease (normal drinking patterns) represents a new steady state, this might restrict the vasopressin neuron's range of response to any subsequent alterations in fluid homeostasis.

Title of Study

Effects of Weightlessness on Neurotransmitter Receptors in Selected Brain Areas

Science Discipline

Neuroscience

Investigator	Institute
J.D. Miller	University of California, Davis

Co-Investigator(s)	Institute
McMillen, B.	East Carolina University
Murakami, D.M.	University of California, Davis
McConnaughey, M.M.	East Carolina University
Williams, H.L.	East Carolina University
Fuller, C.A.	University of California, Davis

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 415; Hardware p. 540-45, 548-9

Objectives/Hypothesis

A number of physiological responses to the microgravity environment have been previously described. For example, temperature regulation, fluid volume and water intake, calcium metabolism and the neuromuscular control of movement are altered under microgravity. Such adaptations to microgravity may be mediated by corresponding changes in brain neurotransmitter dynamics. This study examined the effect of weightlessness on the neurotransmitter receptors in selected areas of the brain of space-flown rats.

Approach or Method

Six flight and six control rats were sacrificed and standard receptor binding assays for receptor number and affinity were performed. Brains were dissected so that the hippocampus and posterior cortex area could be saved for assays, including serotonin, dopamine, noradrenergic, cholinergic and GABA measurements. The Mg-dependent Na^+/K^+ ATPase activity was determined by colorimetric assay of Pi formed from trisATP added to cortical membranes. Group sizes varied from three to six depending on the necessity of pooling tissues.

Results

Data indicate that few receptor changes occurred in the microgravity. When receptor changes did occur, they appeared to be restricted to a particular terminal field, suggesting that microgravity affected terminal mechanisms (e.g., release and uptake) differently, rather than exerting a generalized effect on the projection neuron. The increase in $5HT_1$ receptor in the hippocampus may reflect altered neuromodulation in this area by serotonergic neurons originating in the raphe nuclei. As it has been suggested that one major function of the hippocampus is to serve as a spatial map of the environment, perhaps the transition to microgravity may necessitate major changes in any spatial map of the environment. The $5HT_1$ receptor may play a role in such a modification. Similarly, the flight-associated marginal decrease in D_2 binding in the stratum might reflect a down-regulation induced by heightened dopaminergic activity in the nigra, associated with novel motor activity under microgravity.

Title of Study
Otoconial Morphology in Space-Flown Rats

Science Discipline
Neuroscience

Investigator	Institute
M.D. Ross	University of Michigan

Co-Investigator(s)	Institute
none	

Research Subject(s)
Rattus norvegicus (Sprague Dawley Rat)

9 Flight Male

Ground-Based Controls
9 Simulated Flight Control

Key Flight Hardware
Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information
Mission p. 92-100; Publications p. 415-6; Hardware p. 540-45, 548-9

Objectives/Hypothesis
Weightlessness imposes a new bias against which translational accelerations must be judged. One question to be answered by space flight is whether gravity receptors will show degenerative changes during short- or long-term exposures to microgravity. The ultrastructural study of inner ears obtained from space-flown rats and from age-matched, ground-based controls is a first step in attempting to answer this question. This study was to determine whether the system adjusts to this change in bias induced by exposure to microgravity by undergoing visible alteration or degeneration, or more subtle adaptive processes.

Approach or Method
Inner ear tissues were obtained from three rats perfused intravascularly, and inner ears of an addition six rats were fixed. Macular tissues were prepared for ultrastructural study. Otoconial complexes were removed during dehydration and mounted on stubs for study in a scanning electron microscope. Approximately half of the masses were positioned upright and the others with the underside exposed.

Results
Otoconia of control and flight rats showed only normal configurations; there were no signs of degeneration in any of the flight specimens. It seems possible that instead of demineralization, a slight increase in otoconial mass occurred. This may be because the loading on the receptor may be tied to the functioning of the system—that is, to a species' requirements for resolving translational accelerator forces with respect to gravitational attraction. Species differences could account for the fact that an increase in number of utricular otoconia occurred in the space-flown rat, while an increase in their size was observed in a study of space-flown amphibia. Also, in space-flown rats, tiny otoconia appeared to be growing within organic material at the surfaces of already existing otoconia; and in the sacculus, otoconia were achieving more rounded body surfaces than was typical of controls. These observations suggested that in a mature system, it may be easier to grow or spawn new otoconial substance on already existing units rather than to produce otoconia *de novo*.

Title of Study

Reduction of the Spermatogonial Population in Rat Testes Flown on Spacelab 3

Science Discipline

Regulatory Physiology

Investigator	Institute
D.E. Philpott	NASA-Ames Research Center

Co-Investigator(s)	Institute
Sapp, W.	Tuskegee Institute
Williams, C.	Tuskegee Institute
Stevenson, J.	NASA-Ames Research Center
Black, S.	Tuskegee Institute
Corbett, R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

7 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 416; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Testes have been shown to be affected by space flight, immobilization and hypergravity, and are extremely sensitive to cosmic radiation. The site of action of these various environmental changes and the mechanisms by which they interfere with both spermatogenesis and steroidogenesis requires further investigation. This study examined the effects of space flight on spermatogonia in rat testes.

Approach or Method

Following sacrifice twelve hours postflight, the testes were removed, weighed, and immediately slit open and immersed in Triple Fix. Six blocks were produced from each testes. All of the samples were treated with 1% osmotic acid for one hour, dehydrated in acetone, infiltrated with Epon-Araldite, and polymerized at 60 °C. Two-micron cross sections of the tubules were cut on a microtome, mounted on slides, and stained. Alternate sections containing maturation stage six were used to count the surviving spermatogonia.

Results

The average weight loss of the flight rat testes was 7.1% as compared to the controls. Counts of the stage six spermatogonial cells showed a significant decrease (7.5%) in cell population. The testes is known to be very sensitive to many environmental factors, including radiation and stress, and dosimetry from previous Shuttle flights indicated a dose factor of approximately 0.05 rad would occur in the animal area. Since it would take about one rad of cosmic rays to reduce the measured cell population by the observed amount, radiation cannot be considered the primary cause; stress from adapting to weightlessness and the final jet flight or other factors must also be considered. These findings need to be repeated with accurate dosimetry to determine if radiation had any effect. Also, additional measurements need to be made to determine the role stress has played in decreasing the weight and population of spermatogonial cells.

Title of Study

Biochemical and Morphological Evaluation of the Effects of Space Flight on Rat Salivary Glands

Science Discipline

Regulatory Physiology

Investigator	Institute
M.I. Mednieks	National Institutes of Health

Co-Investigator(s)	Institute
Hand, A.R.	National Institutes of Health

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control; 3 Intact Control (laboratory maintained)

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 416; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Studying salivary gland biochemistry and morphology in experimental animals can yield information regarding general hormonal and environmental responses, specific reactions affecting the oral cavity, as well as comparative aspects of exocrine gland function. Environmental stimuli such as the action of catecholamines are known to result in altered cell morphology and in changes of cyclic AMP-dependent protein kinase (cA-PK) activity and cellular localization. In this experiment, the biochemical and morphological changes in salivary glands of space-flown rats were examined.

Approach or Method

Tissues were fixed and processed for electron microscopy. Salivary glands were trimmed, homogenized, and separated into a soluble and particulate fraction by centrifugation. The fractions were assayed for protein kinase activity, and photoaffinity labeled to determine the distribution of protein kinase. A photoaffinity probe (^{32}P-labeled azido analog of cAMP) was used to determine the compartmental distribution of the R subunits in salivary gland cells.

Results

Several aspects of phosphorylative protein modification in rat salivary glands are apparently influenced by space flight conditions. Endogenous protein phosphorylation was increased in the parotid and in the sublingual glands of flight animals, while measurements of cA-PK activity using an exogenous substrate showed no significant difference in the flight animals. An increase in photoaffinity labeling of regulatory subunits in the parotid cell particulate fractions from flight animals was noted when compared to controls. Changes in cA-PK holoenzyme association and subcellular subunit distribution suggest alterations in reactions which are mediated via cyclic AMP, observations which are consistent with the reported decrease in circulating catecholamines during simulated weightlessness. Testing human saliva or salivary glands after space flight may yield useful indices of cellular reactions related to catecholamine metabolism and thus afford some insight into possible stress-associated responses.

Title of Study

1,25-Dihydroxyvitamin D_3 Receptors in Space Flown vs. Grounded Control Rat Kidneys

Science Discipline

Regulatory Physiology

Investigator	Institute
D. Mangelsdorf	University of Arizona

Co-Investigator(s)	Institute
Marion, S.	University of Arizona
Pike, J.	University of Arizona
Haussler, M.	University of Arizona

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

5 Flight Male

Ground-Based Controls

5 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 416-7; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Under conditions of hypogravity, the skeleton undergoes a significant reduction in bone mineralization. In a weightless environment, a quantitative or qualitative change in receptors could effectively inhibit the normal action of 1,25-dihydroxyvitamin D_3 to retain calcium. Kidneys from rats in control and flown animals were studied to examine the possibility that changes in 1,25-dihydroxyvitamin D_3 receptors may be responsible for inhibiting 1,25-dihydroxyvitamin D_3's normal ability to retain calcium in space-flown kidneys.

Approach or Method

The kidneys from five flight and five ground control animals were prepared postflight, flash frozen, and stored at -70°C until used. Analysis of kidney 1,25-dihydroxyvitamin D_3 receptors followed the hormone binding assay protocol (Scatchard Analysis). An aliquot of cytosol was reserved for Lowry protein determination. Remaining cytosol was then incubated in duplicate aliquots with increasing concentrations of tritium-labeled $1,25(OH)_2D_3$ in the presence or absence of hundredfold excess nonradioactive hormone. Specifically bound hormone was determined by filter assay, and resultant data were plotted as a saturation curve of specific hormone-receptor binding and transformed by Scatchard analysis to yield the binding dissociation constant (K_d) and receptor number (expressed as fmol receptor/mg protein).

Results

Statistical analysis of the data demonstrate no significant qualitative or quantitative difference between $1,25(OH)_2D_3$ receptors in kidneys of space-flown and control rats. Data suggest that kidney $1,25(OH)_2D_3$ receptors do not play a vital role in regulating hypogravity-induced renal calcium excretion. Instead, results support a view in which the kidneys are reacting normally by excreting calcium in response to an artificially induced state of hypercalciuria. Because this condition is mediated by increased bone demineralization, it is likely that the regulating factor(s) are proximal to the bone itself. Another important caveat to interpreting this data is the twelve-hour postflight time lag before animal sacrifice.

Title of Study

Hepatic Enzymes of Sphingolipid and Glycerolipid Biosynthesis in Rats from Spacelab 3.

Science Discipline

Regulatory Physiology

Investigator	Institute
A.H. Merrill	Emory University School of Medicine

Co-Investigator(s)	Institute
Wang, E.	Emory University School of Medicine
Hargrove, J.	Emory University School of Medicine

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Modules

More Information

Mission p. 92-100; Publications p. 417; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Lipid metabolism is a major function of liver, which synthesizes these molecules for membranes, bile and lipoproteins. The activity ratio of serine palmitoyltransferase (SPT) and glycerol 3-phosphate acyltransferase (GPAT), the initial enzymes of sphingolipid and glycerolipid synthesis, is one determinant of tissue lipid composition. Since changes have been observed in some of the enzymes of lipid metabolism in livers from rats under weightless conditions aboard Cosmos, the activities of these key enzymes, SPT and GPAT, were studied in the rats of Spacelab-3.

Approach or Method

Microsomes from liver samples obtained from flight and control rats were assayed for SPT, GPAT, and protein. The amount of sphinogomyelin (SM) in liver was determined by extracting the phospholipids, performing thin-layer chromatography, and quantifying the phosphate in SM. Liver and body weights were considered in the analysis of hepatic metabolism.

Results

SPT activities of flight rats were significantly lower (approximately half) than controls, whereas GPAT activities were not significantly different, nor were liver and body weights, nor weight change during the experiment. Microsomal protein for flight rats was 33% lower than controls, and there were no differences observed in SM content. This may indicate that the major effects of altering the rate of long-chain base synthesis will be found in glycolipids, or that SM levels require longer to come to a new equilibrium, since this phospholipid is generally thought to have a slow turnover rate. These findings of specific changes in hepatic SM metabolism with space flight, though, suggest adjustments of cellular membranes to zero gravity. The observed decrease in flight SPT may reflect cellular adjustments to microgravity, or yet unknown hormone changes that affect this pathway.

Title of Study

Hepatic Enzyme Adaption in Rats after Spaceflight

Science Discipline

Regulatory Physiology

Investigator	Institute
J.L. Hargrove	Emory University School of Medicine

Co-Investigator(s)	Institute
Jones, D.	Emory University School of Medicine

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 417; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Metabolic breakdown of pharmaceutical agents, nutrients, and many hormones begins in the liver, and the numerous hepatic enzymes that regulate these catabolic functions respond adaptively to environmental and biochemical changes. The ability to adapt to microgravity during prolonged space flight requires biochemical adjustments that follow changes such as increased secretion of adrenal hormones. This study was to determine whether hepatic enzyme concentrations change during space flight.

Approach or Method

Livers removed from flight and control animals postflight were minced, homogenized and centrifuged. The supernatant was removed and samples were recentrifuged to prepare microsomes and cytosols. Enzymes were determined by standard spectrophotometric techniques, and glycogen was determined by the anthrone reaction.

Results

There was a twenty-fold greater glycogen content in livers of animals after spaceflight than in ground controls, although the enzymatic basis for this change was not explored. The microsomal protein, cytochrome P-450, was reduced in the flight tissue (obtained twelve hours after the Shuttle landed). The assay used measures all forms of this enzyme; therefore, study should be extended to examine which forms are altered and the possible metabolic consequences thereof. Glutathione S-transferase, tyrosine aminotransferase, and cytochrome b5 were not statistically different in the two groups. To learn whether these biochemical changes affect drug and nutrient metabolism, and influence changes observed in other tissues, will be of both scientific and practical value.

Title of Study

Plasma Renin Concentrations of Rats Orbited for 7 Days Aboard NASA Spacelab 3

Science Discipline

Regulatory Physiology

Investigator	Institute
D.K. Hartle	Emory University School of Medicine

Co-Investigator(s)	Institute
Inge, W.	Emory University School of Medicine

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

6 Flight Male

Ground-Based Controls

6 Simulated Flight Control; 16 Laboratory Control (anesthesia control)

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 417; Hardware p. 540-45, 548-9

Objectives/Hypothesis

There are several cardiovascular, hormonal and neural mechanisms regulating renin secretion that may be significantly affected by the physiological adaptations to the stresses of space flight and microgravity. The renin-angiotensin-aldosterone system defends the extracellular fluid compartment and blood pressure by promoting positive sodium balance and enhancing vasoconstrictor tone. Atriopeptin III augments shifts in extracellular fluid and may cause contraction of the extracellular fluid compartment by promoting diuresis and natriuresis. This study attempted to detect an alteration in renin secretion in space-flown rats.

Approach or Method

Plasma samples were obtained after centrifugation of trunk blood collected at sacrifice of six flight and six ground control rats. A follow-up experiment with a group of sixteen rats was performed to test whether halothane anesthesia or the decapitation procedure affected renin release in either the flight or control rats. Plasma Renin Concentrations (PRC) were estimated by measuring the conversion of rat renin substrate to angiotensin I using radioimmunoassay.

Results

No significant differences were found in PRC between flight and control animals, although the flight mean was lower. Neither halothane anesthesia nor decapitation produced a significant increase in PRC above the levels measured in conscious control rats. Due to the twelve-hour delay between re-entry and sampling, all renin measured was probably secreted in the postflight period, so the PRC of flight rats do not indicate levels during flight, but only the levels obtained by flight animals during the twelve-hour recovery period. In summary, it was predicted that under conditions of microgravity, the tonic secretion of atriopeptin III may cause contraction of the extracellular fluid compartment by its diuretic and natriuretic actions. In addition, through its ability to inhibit renin secretion and interfere with the stimulation of aldosterone secretion, atriopeptin III may concomitantly depress the opposing influences of the renin-angiotensin-aldosterone that defend the extracellular fluid compartment.

Title of Study

Hematologic Parameters of Astrorats flown on Spacelab-3

Science Discipline

Regulatory Physiology

Investigator	Institute
R.D. Lange	University of Tennessee

Co-Investigator(s)	Institute
Andrews, R.	University of Tennessee
Gibson, L.	University of Tennessee
Wright, P.	University of Tennessee
Jones, J.B.	University of Tennessee

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

12 Flight Male

Ground-Based Controls

12 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 418; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Astronauts have experienced a mild anemia following space flight. Examining the hematologic status of rats similarly exposed to altered gravity conditions may provide insight into the source of this anemia. The object of this study was to determine the effects of microgravity on several hematologic parameters in rats flown on Spacelab-3.

Approach or Method

Basic hematologic parameters were obtained by the usual laboratory methods. Parameters included hematocrit, blood cell counts, erythropoietin determination and bone marrow and spleen differential counts. Erythroid colonies were examined and counted on days three, five, six, seven and eight. Only days three and six were reported. Logistically, it was not possible to perform isotope studies to determine red cell mass and plasma volume.

Results

The small flight animals demonstrated a significant increase in hematocrits, red blood cell counts, hemoglobins and peripheral blood percentages of neutrophils as well as a decrease in percentage of lymphocytes. Erythropoietin determinations were similar for the two groups as were the bone marrow and spleen differential counts. *In vitro* clonal assays demonstrated an increased erythroid colony formation of flight animal bone marrow cells at Epo doses of 0.02 and 1.0 U/ml but not at 0.20 U/ml. The changes in red cell parameters could be caused by a decrease in plasma volume. Isotopic studies, not possible in this study, would confirm this hypothesis by enabling determinations of red cell mass and plasma volumes.

Title of Study

Microgravity Associated Changes in Pituitary Growth Hormone (GH) Cells Prepared from Rats Flown on Spacelab 3

Science Discipline

Regulatory Physiology

Investigator	Institute
W. Hymer	Pennsylvania State University

Co-Investigator(s)	Institute
Grindeland, R.	NASA-Ames Research Center
Farrington, M.	Pennsylvania State University
Fast, T.	NASA-Ames Research Center
Hayes, C.	Pennsylvania State University
Motter, K.	Pennsylvania State University
Patil, L.	Pennsylvania State University

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

12 Flight Male

Ground-Based Controls

12 Simulated Flight Control

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module

More Information

Mission p. 92-100; Publications p. 418; Hardware p. 540-45, 548-9

Objectives/Hypothesis

Preliminary results from a rat pituitary cell culture experiment flown on STS-8 indicated that subsequent release of growth hormone (GH) from these cells at unit gravity might be impaired relative to that from ground-based control cells. Since GH exerts control over metabolic activities and macromolecule biosynthesis in a number of target tissues, impaired GH cell function in microgravity could conceivably participate in atrophy of those targets.

Approach or Method

Pituitary glands were dissociated into single cell suspensions with viabilities greater than 95%. GH cell function in somatotrophs prepared from pituitary glands of rats exposed to microgravity were compared with those from corresponding controls. Somatotroph numbers were determined by flow cytometric immunofluorescence. Western blot analysis of alkaline (pH 8) cell extracts or culture media was done by electrophoresis followed by staining for GH variants by enzyme-linked immunoassay. For culture, $2.5x10^3$ cells/well were maintained for six days with an intervening medium change on the third day. GH was assayed by RIA or 3T3 cell bioassay. For determination of GH cell function *in vivo*, cells were implanted into the lateral ventricles of 100 g rats using the hollow fiber encapsulation procedure. After sixteen days, tibial plates of recipients were measured to provide an index of long bone growth resulting from the implantation.

Results

Pituitary growth hormone cells from glands of rats flown on SL-3 contained two to three times more intracellular hormone than controls, but released significantly less GH in subsequent *in vitro* and *in vivo* tests. After implantation into hypophysectomized rats, cells from both sizes of flight rats released ~50% as much GH relative to those from the control group. These diminished GH secretory patterns cannot be attributed simply to changes in variant forms of the GH molecule(s), though, since Western blot profiles in both intracellular and secreted GH revealed only minor differences in concentration and number of GH variants. Since the balance between somatostatin and GH releasing hormone presumably regulates hormone secretion *in vivo*, it is possible that microgravity alters their ratio to bring about high intracellular GH levels and lower release rates. As encapsulated cells were in an environment where they were exposed to hypothalamic regulatory peptides, one could also suggest that experimental cells were less sensitive to these peptides as a result of microgravity.

Title of Study

Homeostasis and Biological Rhythms in the Rat During Spaceflight

Science Discipline

Regulatory Physiology

Investigator	Institute
C.A. Fuller	University of California, Davis

Co-Investigator(s)	Institute
none	

Research Subject(s)

Rattus norvegicus (Sprague Dawley Rat)

4 Flight (BTS implanted) Male

Ground-Based Controls

4 Simulated Flight Control (BTS implanted)

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Rodent Cage Module; Biotelemetry System (BTS)

More Information

Mission p. 92-100; Publications p. 419; Hardware p. 466-7, 540-45, 548-9

Objectives/Hypothesis

Homeostatic regulation of various physiological and behavioral systems may be altered as a function of the ambient gravitational environment of the organism. Changes in homeostasis have been observed in these and other systems as a result of chronic exposure to a hyperdynamic environment induced by centrifugation. Life science research capabilities are now being extended into the realm of the hypodynamic environment by research capabilities aboard spacecraft. This study examined the regulation of body temperature and heart rate in rats with biotelemetry implants.

Approach or Method

Four rats were implanted preflight with a biotelemetry transmitter capable of sensing and transmitting information on heart rate and deep body temperature. The telemetry data from the animals was monitored during the period which Spacelab was activated (approximately from eight hours after launch to six hours prior to re-entry). The average 24-hour waveforms of body temperature in preflight and flight conditions were examined. Four ground control animals were similarly implanted and monitored.

Results

Microgravity altered the steady state regulation of heart rate and body temperature. During the preflight conditions the animals demonstrated no net change in phase relationship, with the mean period 23.9 ± 0.2 over the course of the preflight study, while inflight, the phase of all the animals consistently delayed such that the average period of the temperature rhythm inflight was 24.4 ± 0.3 hours. A longer flight will be necessary to identify whether or not the animals are free-running with a period independent 24-hours or rather simply showing an internal phase angle shift which had not reached a steady state during the seven-day flight. Heart rate phase rhythm was stable in both conditions, with a mean period of 23.9 ± 0.2 in either. The heart rate itself was, however, depressed inflight, the possible result of a reduced load on the cardiovascular system in space or a resetting of some other component within this regulatory system. Data suggest that normal expression of the circadian timing system is extensively modified in microgravity.

Title of Study

Early Adaptation to Altered Gravitational Environments in the Squirrel Monkey

Science Discipline

Regulatory Physiology

Investigator	Institute
C.A. Fuller	University of California, Davis

Co-Investigator(s)	Institute
none	

Research Subject(s)

Saimiri sciureus (Bolivian Squirrel Monkey)

2 Flight Monkeys Male

Ground-Based Controls

6 Centrifuged (1.5 g) Control Monkeys; Stationary Control Monkeys

Key Flight Hardware

Research Animal Holding Facility (RAHF); RAHF Primate Cage Module

More Information

Mission p. 92-100; Publications p. 419; Hardware p. 540-45, 546-7

Objectives/Hypothesis

Behavioral observations from the few non-human primates that have been flown to date indicate that primates are susceptible to symptoms resembling space adaptation syndrome (SAS) experienced by astronauts. The etiology and underlying mechanisms of SAS are not currently understood. Many ground-based tests for SAS sensitivity examine various vestibular reflex sensitivities using acute phasic stimuli. However, the microgravity of space flight is a tonic stimulus which is maintained at relatively constant levels. This study compared ingestive response in microgravity with ingestive responses to an artificially induced tonic gravitational stimulus on Earth.

Approach or Method

The feeding behavior of two squirrel monkeys flown in Spacelab-3 was compared to that of six animals exposed to 1.5 g via centrifugation for a similar period of time. The feeding, drinking and activity levels of the animals were continuously recorded for the duration of the mission. Postflight analyses of the animals consisted of behavioral observations without recording of any physiological data.

Results

In both groups of animals, the influence of an altered dynamic environment was variable on the feeding behavior of the individual monkeys. The kinetics of the animal's recovery show inhibition in feeding primarily during the active period when the lights are on. This results in a reduction of both the mean and amplitude of the feeding rhythm. Recovery of all animals is virtually completely accomplished within 96 hours. Whether this is truly a SAS occurring in either group of squirrel monkeys remains to be determined. Some of the centrifuged animals and one flight monkey showed a series of symptoms similar to those observed in space flight crews: animals were lethargic and reticent to move about the cage; they adopted a sleep posture and showed very little reactivity when moved. These are conditions crew members often equate with maximum relief of SAS symptoms. Thus, the responses to steady-state changes in the ambient gravitational environment may be similar for both hyper- and hypodynamic (microgravity) fields.

Title of Study

Gravity-Induced Lignification in Higher Plants

Science Discipline

Plant Biology

Investigator	Institute
J.R. Cowles	University of Houston

Co-Investigator(s)	Institute
Lemay, R.	University of Houston
Jahns, G.	University of Houston

Research Subject(s)

Pinus elliotti Engelm (Pine Seedlings)

Vigna radiata (L.) Wilczek (Mung Bean), *Avena sativa* L. cv. (Oat)

Ground-Based Controls

Synchronous Mung Beans, Oat, and Pine Seedlings

Key Flight Hardware

Plant Growth Unit [PGU]

More Information

Mission p. 101-3; Publications p. 419; Hardware p. 506-7

Objectives/Hypothesis

The appearance of lignin in higher plants coincides with development of a terrestrial vertical growth habit and is generally considered to be the critical structural polymer needed for upright growth against gravity. In view of this evolutionary coincidence it has been postulated that lignin deposition is mediated by gravity. The purpose of this investigation was to determine the effects of microgravity upon the production of lignin in higher plants.

Approach or Method

Two miniature greenhouses, called plant growth units (PGUs), containing four-day and ten-day old pine seedlings, mung bean seeds, and oat seeds, were flown as part of the Spacelab-2 payload. The growth chambers were sealed and the atmosphere of each chamber was exchanged with gas mixtures containing known amounts of oxygen and carbon dioxide. During flight, temperature and lamp status data were monitored from a control panel. Three times a day, crew members checked the temperatures inside the growth chambers; twice a day, gas samples and photographs were taken. After landing, the seedlings were photographed and measured, and subsequently they were sectioned and analyzed for lignin content and related enzyme activities. An identical group of plants were later grown as ground controls, utilizing the temperatures and gas measurements obtained inflight

Results

The lignin content of flight seedling was significantly reduced in all three plant species in comparison to controls. In the youngest pine seedlings (four days old at launch, twelve days old at harvest), lignin content of flight seedlings averaged 13% less than controls. In the oldest pine seedlings (ten days old at launch, eighteen days old at harvest), lignin content of flight seedlings was 8% less than controls. Lignin content in flight mung beans and oats averaged 24% and 23% less than controls, respectively. In all cases, the difference in lignin content was statistically significant at least at the 0.01% level. This reduction in lignin in all three species grown in microgravity provides direct evidence that gravity is an important parameter in lignification.

Title of Study
Animal Enclosure Module Inflight Test

Science Discipline
Animal Maintenance

Investigator	Institute
D.J. Weber [Student Investigator]	Hunter College High School, New York

Co-Investigator(s)	Institute
Holton, E.R. [Science Advisor]	NASA-Ames Research Center
Smith, M.C. [Science Advisor]	NASA-Johnson Space Center
LeBlanc, A.	NASA-Johnson Space Center
Johnson, P.C.	NASA-Johnson Space Center
Corporate Sponsors	
Kessler, T.	General Dynamics
Crenshaw, J.	General Dynamics
Larson, D.	Pfizer, Inc.

Research Subject(s)
Rattus norvegicus (Wistar Rat)

6 Flight Male

Ground-Based Controls
3 Ground Controls

Key Flight Hardware
Animal Enclosure Module (AEM)

More Information
Mission p. 112-5; Publications p. 408; Hardware p. 460-61

Objectives/Hypothesis
The Animal Enclosure Module (AEM) was developed for a SSIP experiment flown on STS-41B. The purpose of this study was to test the ability of the AEM to maintain healthy rats in space with no dangers to crew safety, as this was the first time a cage of animals was flown in the crew compartment of the Shuttle. The major safety concerns involved microbial, particulate, and odor contamination of the crew atmosphere.

Approach or Method
The AEM was successfully flown for the first time with six Specific Pathogen Free (SPF) male albino rats of the Lewis Wistar strain (the standard rodent research subject), 56 days old and an average of 275 grams at launch. Contamination was to be avoided by the use of germ-free (SPF) rats, microbial filters on the intake and exhaust areas of the AEM, and airtight seals around certain areas of the AEM. A control group of three rats was maintained on the ground for comparative purposes.

Results
All six rats were healthy at the end of the flight. The flight rats consumed less food and did not gain weight at the expected rates, compared to the ground controls. This was due to the AEM food delivery system in which food was attached to the cage slides, while ground control cages had a more conventional food system. The water supply of half the flight rats was depleted before the end of the mission, and the water supply for the rest of the rats was nearly gone. As a result, minor changes in AEM food and water systems were recommended. In addition, it was determined that the air flow rate through the AEM needed to be increased in order to improve the removal of the cage waste products.

Title of Study

Effects of Weightlessness on Arthritis

Science Discipline

Musculoskeletal

Investigator	Institute
D.J. Weber [Student Investigator]	Hunter College High School, New York

Co-Investigator(s)	Institute
Holton, E.R. [Science Advisor]	NASA-Ames Research Center
Smith, M.C. [Science Advisor]	NASA-Johnson Space Center
Corporate Sponsors	
Kessler, T.	General Dynamics
Huston, G.	General Dynamics
Larson, D.	Pfizer, Inc.
Otterness, I.	Pfizer, Inc.

Research Subject(s)

Rattus norvegicus (Wistar Rat)

6 Flight (3 Healthy, 3 Inoculated)

Ground-Based Controls

6 Basal, 6 Tail-Suspension, 6 Environmental Control

Key Flight Hardware

Animal Enclosure Module (AEM)

More Information

Mission p. 112-5; Publications p. 408-9; Hardware p. 460-61

Objectives/Hypothesis

This experiment was to study the effects of hypogravity on the course of adjuvant-induced arthritis and to further evaluate the Animal Enclosure Module (AEM) for housing rats in Shuttle experiments. It was hypothesized that arthritis symptoms may be alleviated in microgravity, as was indicated in ground-based experiments simulating weightlessness with hindlimb unloading.

Approach or Method

The AEM was flown with three healthy rats and three arthritic rats. Arthritis was induced in the animals by the injection of Freund's adjuvant into the hind paws. Ground control groups included a total of six healthy and six arthritic rats. All rats were germ-free (gnotobiotic). Food and water consumption and body weight data were recorded for all animals. Postflight autopsies of the rats, including histologic and radiologic tests, were performed to determine if weightlessness had a therapeutic effect on adjuvant arthritis.

Results

Space flight did not inhibit the development of adjuvant arthritis compared to ground controls; no significant differences were observed in the degree of swelling in the injected hind paws. The spread of arthritis, though, was observed to be less extensive in flight rats compared with prior ground-based studies, indicating some possible beneficial effects of weightlessness. The results may have been affected because re-entry occurred while the systemic stage of the disease was still developing. Further studies are required to fully understand the effects of gravity on arthritis. Healthy (uninjected) flight rats consumed more food during the flight and weighed more at the end of the mission than comparable ground controls. The AEM was able to successfully maintain all rats during space flight.

Title of Study

The Effects of Weightlessness in Spaceflight on the Healing of Bones

Science Discipline

Musculoskeletal

Investigator	Institute
A.I. Fras [Student Investigator]	Binghamton Central High School, New York

Co-Investigator(s)	Institute
Fisher, H. [Teacher Advisor]	Binghamton Central High School
Holton, E.R. [Science Advisor]	NASA-Ames Research Center
Smith, M.C. [Science Advisor]	NASA-Johnson Space Center
Corporate Sponsor	
Marshall, G. [Science Advisor]	Orthopedic Hospital, Los Angeles
Kirchen, M.E.	Orthopedic Hospital, Los Angeles
O'Connor, K.M.	Orthopedic Hospital, Los Angeles
Sweeney, J.R.	Orthopedic Hospital, Los Angeles
Kessler, T.	General Dynamics
Huston, G.	General Dynamics

Research Subject(s)

Rattus norvegicus (Wistar Rat)

4 Injured Flight Rats — Male

Ground-Based Controls

4 Injured Suspended Rats; 4 Injured

Key Flight Hardware

Animal Enclosure Module (AEM)

More Information

Mission p. 112-5; Publications p. 420; Hardware p. 460-61

Objectives/Hypothesis

This experiment was designed to study the effects of space on changes in bone growth and repair. The experiment was originally flown on STS-51L, the Space Shuttle Challenger, which was tragically lost 73 seconds into flight as a result of a fuel leak. The re-manifested experiment extended previous objectives by comparing the effects of the gravity and microgravity environments on bone healing, with addition of the tail-suspension model to the ground controls. The tail-suspension model allowed the aspect of weight-bearing to be differentiated from other gravity effects by elevating the rear legs of the animal during the control experiment, and hence removing the animal's weight from the bones to be examined.

Approach or Method

Weight-bearing, suspended, and microgravity (flight) environments were used to study fracture repair. The five-day flight allowed the comparison of early stages of callus formation using histologic criteria. Seven-month-old rats underwent a right midshaft fibular osteotomies. A bone saw and 0.8 mm bur were used in performing the osteotomies. The time of suspension was equal to the time inflight, and postflight all groups were euthanized simultaneously. Histologic examination of the fracture was performed on the injured fibula from each rat.

Results

In each of the three groups, a callus had formed. Angiogenesis (AG), primitive mesenchymal cell (PMC) ingrowth, chondrogenesis and periosteal new bone characterized the calluses from weight-bearing bones. Calluses from the suspended group were not as well developed, in that AG, PMCs and cartilage cells were dominant; there was no new bone in the calluses or periostea. Fracture healing in the flight group was the least well developed: predominant features were AG and PMC ingrowth; chondrogenesis and periosteal activity were minimal; and there was no new bone formation. Comparing all three environments, it was concluded that weight-bearing has a positive effect on callus formation, while the suspended and weightless environments delay bone fracture healing. This delay indicates the need for investigation of the physiological parameters that contribute to the process of fracture healing in these environments.

Title of Study

Effects of Microgravity on Growth Hormone Concentration and Distribution in Plants

Science Discipline

Plant Biology

Investigator	Institute
R.S. Bandurski	Michigan State University

Co-Investigator(s)	Institute
Schulze, A.	Michigan State University
Jensen, P.J.	Michigan State University
Desrosiers, M.	Michigan State University
Buta, J.G.	U.S. Department of Agriculture

Research Subject(s)

Zea mays (corn seeds)

104 Flight (52 frozen inflight)

Ground-Based Controls

104 Flight Backup (Synchronous)

Key Flight Hardware

Plant Canister; Passive Freezer; Temperature Recording System-Modification 1 (ATR-4)

More Information

Mission p. 104-5; Publications p. 420; Hardware p. 500-501, 504-5, 554-5

Objectives/Hypothesis

The absence of a well defined neuronal system in plants should simplify the detection of gravity effects at the cellular and molecular level. Plants grown in microgravity may be used to detect the adaptations that have occurred during growth in Earth gravity, allowing the potential isolation of the genes which control the plant's responses and structures produced because of gravity. This experiment was to study the effect of gravity on the concentration and distribution of the plant growth hormone, indole-3-acetic acid (IAA or auxin), as a possible indicator of microgravity effects on plant growth.

Approach or Method

Zea mays seeds (soaked) were maintained in special filter paper inside Plant Canisters, in total darkness throughout mission. After four days of flight, two of the four canisters were be placed inside gaseous nitrogen freezers to arrest growth and preserve IAA inside the plant. The two remaining canisters remained untouched for postflight analysis of continued growth. Postflight, measurements were made of the fresh weight, dry weight, dry/fresh weight ratio, free and conjugated IAA, and free and conjugated weight of asorbic acid. The IAA assays employed IAA labeled in the benzenoid ring with six atoms of ^{13}C.

Results

Postflight examination revealed 100% germination and extensive growth. The plant material had an abnormal growth pattern. Tissues of flight plants appeared normal and seedlings differed only in the lack of orientation of roots and shoots. In many cases, the roots and coleoptiles (shoots) grew in parallel, or the shoots were twisted and appeared knotted. Many adventitious roots were produced along the primary root below the seed. Weights and hormone content of flight seedlings, with minor exceptions, did not statistically differ from seedlings grown in similar conditions on the ground. No serious chemical perturbations appear to have occurred in the seedlings during 5.5 days of growth in microgravity. It was concluded that results suggest that the major problem of growing plants in space may lie in providing a substitute vector for orientation of the growth of plant roots in space.

Title of Study

Characterization of *Neurospora crassa* Circadian Rhythms in Space

Science Discipline

Immunology/Microbiology

Investigator	Institute
J.S. Ferraro	Southern Illinois University

Co-Investigator(s)	Institute
none	

Research Subject(s)

Neurospora crassa

50 Flight Cultures

Ground-Based Controls

Flight Backup Cultures (Synchronous); Humidity Control; Environmental Controls

Key Flight Hardware

Race Tube Packages; Temperature Recording System-Modification 1 (ATR-4)

More Information

Mission p. 106-8; Publications p. 420; Hardware p. 522-3, 554-5

Objectives/Hypothesis

This experiment was to examine the circadian rhythm of *Neurospora crassa* asexual spore production (conidiation) in the microgravity environment. The objective was to validate results from a previous experiment conducted on STS-9, which suggested an apparent arrhythmicity of 25%. In that experiment, arrhythmicity was reversed by an inflight procedure on day seven, in which cultures were exposed to light and accelerative forces via handling. Rhythmicity was restored and continued throughout the flight, suggesting an endogenous generation. This study was to determine if the biological clock is endogenous to an organism and not merely driven by external cues.

Approach or Method

Cultures were grown in constant light and then transferred to the dark to initiate expression of the conidiation rhythm; two strains were utilized, bd (used in STS-9) and csp. Cultures remained in the dark for the duration of the experiment, excluding inflight marking procedures. The crew marked the fungus growth fronts in the Race Tubes while exposing them to light according to different protocols, utilizing markings at ten hours, and six, nine, and ten days. Measurements of light levels in the middeck area and gas samples within the race tubes were taken on day one to quantify CO_2 or other gas levels which may impact circadian periods. Postflight analysis included assessments of growth rate, morphology, and period rhythmicity based on examination of culture band amplitudes with respect to markings.

Results

Circadian rhythm of conidiation was shown to persist in space and was found to be substantially more robust than that found earlier on the STS-9 experiment. There was a significant increase in the free-running period in space. The increase in period length resulting from space flight was eliminated after exposure to the first white light pulse. Growth rate was significantly increased by exposure to space; however, there was no increase in the variability in the growth rate as previously reported; warmer middeck temperatures may have contributed to this increase. Morphological examinations revealed an apparent increase in the aeial hyphae and possibly a denser growth in space. Results demonstrated that the rhythm persisted in space with minor fluctuations in amplitude and period, suggesting the presence of an endogenously driven circadian oscillator that is modified by environmental factors, including to a minor extent, gravity.

Title of Study

Physiological Systems Experiment

Science Discipline

Musculoskeletal & Immunology/Microbiology

Investigator	Institute
M. Cronin	Genentech, Inc.

Co-Investigator(s)	Institute
Hymer, W.	Pennsylvania State University
Grindeland, R.	NASA-Ames Research Center
Mastro, A.	Pennsylvania State University
Nash, P.	Pennsylvania State University
Tidball, J.	
Quan, D.	
Battersby, J.	
Hancock, W.	
Schwall, R.	
Clark, R.	

Research Subject(s)

Rattus norvegicus (Wistar Rat)

8 Flight; 8 Flight Protein-Treated Male

Ground-Based Controls

8 Flight Simulated; 8 Flight Simulated Protein-Treated

Key Flight Hardware

Animal Enclosure Module (AEM); Osmotic Minipumps (Genentech, Inc.)

More Information

Mission p. 109-11; Publications p. 421; Hardware p. 460-61

Objectives/Hypothesis

The objective of this experiment was to test the hypothesis that a growth-hormone (GH) deficiency occurs during space flight and that this deficiency contributes to the bone loss and decreased tissue function observed following microgravity exposure. It was expected that replacement with recombinant GH inflight, in combination with adequate nutrition and exercise, would halt the process of bone and tissue degeneration. As the first commercially sponsored life science payload, the experiment was to investigate whether biological changes caused by microgravity were similar enough to Earth-based medical conditions to facilitate pharmacological evaluation of potential new therapies. Other objectives included evaluation of muscle and immune function, which are known to be affected/regulated by GH.

Approach or Method

The experiment included sixteen flight rats, eight of which received the recombinant growth hormone which Genentech, Inc. had developed. Specially designed osmotic pumps were implanted in rats to deliver the GH to the animals in microgravity. The remaining eight rats did not receive the experimental treatment and provided a standard of comparison. Postflight analyses conducted by Genentech, Inc. included some 2,500 biological and physiological measurements, ranging from simple weight measurements to highly sophisticated analyses of their proprietary protein. Additional studies were conducted by investigators from the Center for Cell Research, at Pennsylvania State University.

Results

Not available at time of publication (property of Genentech, Inc.).

Cosmos Program Experiments

Lists of experiments by discipline and reference number can be found in the mission profiles in Section 4, Programs, Missions and Payloads.

Title of Study

Effects of Weightlessness on the Embryonic Development and Aging of *Drosophila*

Science Discipline

Cell/Developmental Biology

Investigator	Institute
J. Miquel	NASA-Ames Research Center

Co-Investigator(s)	Institute
Philpott, D.E.	NASA-Ames Research Center
Lundgren, P.R.	NASA-Ames Research Center
Binnard, R.	NASA-Ames Research Center
Turnbill, C.E.	NASA-Ames Research Center

Research Subject(s)

Drosophila melanogaster (Fruit Fly)

201 Flight, 188 Flight Centrifuged Male/Female

Ground-Based Controls

98 Synchronous, 91 Laboratory

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 421; Hardware p. 455-6

Objectives/Hypothesis

All living organisms have evolved under the influence of Earth's gravity, and, therefore, it is generally assumed that gravity has played a role in shaping structure and function. Previous laboratory work has documented that the aging process of *Drosophila* is strikingly sensitive to altered environments, such as temperature changes and rotation in a clinostat. This study focuses on the aging process of fruit flies which developed and spent their first days of life in space.

Approach or Method

The experimental *Drosophila* population was exposed to weightlessness, while an equal number of flies housed in a centrifuge at approximately 1 g served as in-flight controls. Synchronous and vivarium groups served as ground controls. All flies were individually weighed in a Cahn electric balance. Other parameters included: vitality, as expressed by negative geotaxis and mating; external morphology and age-associated degenerative changes, as demonstrated by gross photography and scanning electron microscopy; glycogen content of the thorax to estimate muscle energy reserve; and life span.

Results

Apparently, the development of *Drosophila* was insensitive to weightlessness and the aging processes were not influenced, except for a slight reduction in the amount of lipofuscin present in the midgut and Malpighian tubules, the tubular glands of excretory function. The only detrimental effect seemed to be a decrease in the negative geotaxis and mating. It is likely that this decreased mating ability (almost half in both flight groups) was the result of injury to the wing structures (which play a crucial role in *Drosophila* mating), as the consequence of acceleration or other flight stresses unrelated to weightlessness. Otherwise, the weightless flies were identical to controls in all parameters investigated.

Title of Study

Killifish Development in Zero-G on Cosmos 782

Science Discipline

Cell/Developmental Biology

Investigator	Institute
J.R. Keefe	University of Louisville

Co-Investigator(s)	Institute
Scheld, H.W.	University of Houston
Boyd, J.F.	Northrop Services, Inc.
Fuller, P.M.	University of Louisville
Oppenheimer, J.M.	Bryn Mawr College

Research Subject(s)

Fundulus heteroclitus (Killifish)

500 Flight, 500 Centrifuged Eggs

Ground-Based Controls

500 "Dish", 500 Synchronous, 500 Rotated, 500 U.S. Control Eggs

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 421; Hardware p. 455-6

Objectives/Hypothesis

The *Fundulus* embryogenesis experiment was the third in a series of experiments to assess the possible effects of the space environment upon developing organisms. On the Skylab-3 and Apollo Soyuz missions, juvenile fish initially exhibited obvious disorientation reactions (swimming rapidly in loops and circles), but over a period of several days in orbit, they gradually adapted to weightlessness and to dependence on visual cues, while space-hatched fry exhibited no disorientation. The major refinement in this experiment is the use of a 1 g control centrifuge.

Approach or Method

Experimental treatment groups of 500 embryos were comprised of groups of 100 eggs from the each of the five nominal developmental stages. Specimens were kept in Polyethylene bags each containing fifty embryos of a given age and 23 ml sterile filtered 21% Instant Ocean. Treatments included flight stationary, an onboard 1 g centrifuge, and various ground control experiments. The primary data yielded by the experiment was in the form of fixed material for light and electron microscopic analysis, focusing on the vestibular and other sensory regions. Light orientation, rotating striped drum, and geotaxis tests were employed postflight.

Results

Postflight testing of procedures and materials indicates that the probable cause of the high incidence of anomalous development lies in the tape used to label the plastic bags. All morphologically normal hatchlings though, exhibited a typical fright-diving response and there were no apparent differences among treatments with respect to the diving response. Likewise, behavioral testing ascertained that development in weightlessness of Fundulus, from the earliest exposure achievable, has no radical effect upon the vestibular function. Microscopic observations indicated a generally better health in flight animals, with the possible exceptions of those aspects of development in which gravity is required as a cue for establishment of polarity or as a reference stimulus for sensory development.

Title of Study
Effect of Spaceflight on Cell-Mediated Immunity

Science Discipline
Immunology/Microbiology

Investigator	Institute
A.D. Mandel	NASA-Ames Research Center

Co-Investigator(s)	Institute
Balish, E.	University of Wisconsin

Research Subject(s)
Rattus norvegicus (Wistar Rat)

6 Flight Male

Ground-Based Controls
6 Vivarium, 6 Synchronous

Key Flight Hardware
Cosmos 782 Russian Hardware Suite

More Information
Mission p. 126-32; Publications p. 422; Hardware p. 455-6

Objectives/Hypothesis
It has been demonstrated that cell-mediated immune reactions in mammals are thymus-dependent, and that thymus-derived or thymus-dependent lymphocytes (T-cells) are responsible for the reactions of cellular immunity. Rats flown in Cosmos 605 have shown changes in the size of thymus and spleen, suggesting that space flight might have a noticeable effect on the cellular aspect of immune responsiveness. This study examined the effect of space flight on cell-mediated immunity by examining rats infected with *Listeria monocytogen*.

Approach or Method
Both flight and control groups were immunized with 10^6 formalin-killed *Listeria* suspended in Freund's Complete Adjuvant five days prior to flight. Following recovery, lymphocyte cultures were prepared from spleens of all rats, and cultured *in vitro* in the presence of *Listeria* antigens, phytohemagglutinin, concanavalin A, and purified protein derivative (PPD) and measured for their uptake of ^{3}H-thymidine. The uptake of ^{3}H-thymidine by the lymphocytes of immunized flight rats in the presence of specific antigen, was compared with those of immunized ground controls. A Student's T test was used to assess the significance of the data.

Results
The lymphocytes of all rats gave a blastogenic response to phytohemagglutinin and concanavalin A. Although individual rats varied considerably, all flight and immunized control rats gave a blastogenic response to the Listeria antigens and PPD. With several mitogens the lymphocytes of flight rats showed a significantly increased response over the controls. If indeed the increased immune response to PPD in space can be confirmed, it suggests a practical application of the space environment for immunotherapy of tumors. Thus, the data do not support a hypothesis of detrimental effect of space flight on cell-mediated immunity, even suggesting an opposite effect.

Title of Study

Results of Histological Examination of Inguinal Lymph Nodes: Supplementary Report

Science Discipline

Immunology/Microbiology

Investigator	Institute
L.M. Kraft	NASA-Ames Research Center

Co-Investigator(s)	Institute
none	

Research Subject(s)

Rattus norvegicus (Wistar Rat)

6 Flight Male

Ground-Based Controls

6 Vivarium, 6 Synchronous

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 422; Hardware p. 455-6

Objectives/Hypothesis

This study examined the effect of space flight on cell-mediated immunity by examining the inguinal lymph nodes of rats infected with a formalin killed culture of *Listeria monocytogenes* suspended in Complete Freund's Adjuvant prior to flight. Supplementing a larger study, this experiment attempts to obtain more information on how weightlessness affects cells responsible for the development of a specific immunity.

Approach or Method

Inguinal lymph nodes of all rats were received in neutral 10% formalin. They were processed for paraffin embedding, and sections 6 µm thick were stained with hematoxylin and eosin, pyronin-methyl green, and picrofuchsin. Six of the rats were from the vivarium control group (normal laboratory conditions), six were of the synchronous control group (simulated flight), and six were of the flight group.

Results

The most outstanding differences between the flight and ground control groups were: 1) marked, widespread depletion of lymphocytes resulting in much larger pale zones than in controls and 2) the occurrence of numerous foci of pyknotic and necrotic cells together with variable amounts of dust-like debris. The striking increase in the number of necrotic cells, together with evidence of phagocytosis of some cellular debris, is thought to be due to the multitude of stressful conditions of prolonged space flight. Precisely how the increased destruction of lymphoid cells fits with other experimental results must remain an open question for future studies.

Title of Study

Histological Studies on the Tibial Bone of Rats in the 1975 Cosmos 782 Flight: I. Endochondral Osteogenesis; Medullary Bone Turnover

Science Discipline

Musculoskeletal

Investigator	Institute
C.W. Asling	University of California, San Francisco

Co-Investigator(s)	Institute
none	

Research Subject(s)

Rattus norvegicus (Wistar Rat)

6 Flight Male

Ground-Based Controls

6 Vivarium, 6 Synchronous

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 422; Hardware p. 455-6

Objectives/Hypothesis

This experiment concerns the histological evaluation of endochondral ontogenesis in rats subjected to weightlessness in Earth-orbit for nineteen days. Balances between cartilage formation and resorption, and medullary bone formation and resorption were analyzed in the proximal segment of the tibia.

Approach or Method

Tibial lengths, appearance of the proximal tibial epiphysis and metaphysis, and measurements of the bony spongiosa in the latter, were determined for flight rats and compared to ground controls. Fixated samples were stained with hematoxylin and eosin, and Mallory's triple stain (aniline blue, orange G, and acid fuchsin), and studied histologically. Measurements were made whenever possible to provide quantitative support for the qualitative histological evaluations.

Results

Growth retardation was not marked, falling between a negligible level and 25%. Bone formation was slightly impaired in synchronous controls, and to an appreciably greater extent in flight animals. Bone resorption was moderately accelerated in synchronous controls, markedly more so in the flight animals, to an extent under which virtually all preflight medullary bone was removed and in addition a substantial fraction (1/4 -1/2) of that formed during flight was also resorbed. Although the results suggest that disuse atrophy and other restrictions during the experiment account for part of the imbalance, the condition of weightlessness added a considerable further imbalance.

Title of Study

Histological Studies on the Tibial Bone of Rats in the 1975 Cosmos 782 Flight: II. Micrographic Study of the Cortical Bone

Science Discipline

Musculoskeletal

Investigator	Institute
C.W. Asling	University of California, San Francisco

Co-Investigator(s)	Institute
none	

Research Subject(s)

Rattus norvegicus (Wistar Rat)

4 Flight Male

Ground-Based Controls

6 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 422; Hardware p. 455-6

Objectives/Hypothesis

Conceivably, a decrease in the mineral content of a bone (as in hypogravity), could result from a shift in the balance of internal remodeling, in which a smaller proportion of osteons would be of the older, high mineral density types, and a larger proportion of the recently formed and less mineralized type. Based on this hypothesis, a study of rat cortical bone has been made by microradiography, on sample tibia from rats subjected to prolonged weightlessness.

Approach or Method

Thin-ground transverse sections of the tibial cortex, embedded in polystyrene plastic, were microradiographed in contact with high resolution spectrographic film. The resulting films were examined microscopically, and output from a photomultiplier tube was used to represent mineral densities, judged radiographically, from morphometric principles determined from mathematical bases. Resolving power of the system was such that while the lacunae of individual osteocytes were not recognized as "porosity," all but the smallest channels in the bone specimen were thus recognized.

Results

Results indicate that ranges of mineral densities of vivarium controls in three-month-old animals were in accord with findings on human juvenile bone. The synchronous controls showed increased porosity and a shift in mineral balance toward a larger proportion showing low mineral content, suggesting increased resorption. In the flight animals, lower levels of porosity, as compared to controls, and the tendency toward a uniform distribution of mineral values, suggest a sampling error. It is also possible that with the prolonged period between sacrifice and bone fixation, the products of marrow cytolysis may have redistributed mineral contents of adjacent bone so as to obscure any real difference which may have existed.

Title of Study

Mineralization in Teeth and Jaws, as Judged Radiographically, in the Rats of the Cosmos 782 Experiment

Science Discipline

Musculoskeletal

Investigator	Institute
I. Savostin-Asling	University of California, San Francisco

Co-Investigator(s)	Institute
Asling, C.W.	University of California, San Francisco
Ellis, S.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

6 Flight Male

Ground-Based Controls

6 Vivarium, 6 Synchronous

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 422; Hardware p. 455-6

Objectives/Hypothesis

This study presents data on the mineralization of the teeth in rats subjected to prolonged space flight. Although the pitfalls inherent in quantitative radiologic studies were kept in mind, there was an advantage in knowing the resorption in the spongy bone and the ambiguous result on dense bone in the same animals. Special efforts were made to standardize the regions of tooth structure measured, in the hope that masses of tissue in low experimental reactivity might not obscure more highly reactive sites.

Approach or Method

Heads were divided sagittally and x-rayed. Optical densities were measured on the films with a densitometer calibrated in American Standard Diffuse Density units. Limitations were principally: 1) that readings would be taken at some reasonable distance from the apex (region of tooth formation) to reach the mineralized band of structure and 2) that readings would not be over the tip of the tooth since the greatest part of the tooth was in fact closed in thin bone. While the density readings followed a logarithmic scale, the light transmission values were on an arithmetic percentage scale.

Results

Although enamel values in the flight animals, both at recovery and 25 days post-flight, seemed lower than controls, the difference was not significant. Other findings suggest a small amount of mineral loss may have occurred during the experimental period. Mineral repletion was not observed during the recovery period. The thin bone of the mandibular body was slightly reduced in both synchronous and flight rats, but rose to the level of vivarium controls after the recovery period. Changes of similar direction were found in the heavy bone underlying the molar teeth, suggesting that the stimulus of chewing was reduced in these groups, with restoration of a firmer diet during the recovery period increasing masticatory activity and improving bone structure.

Title of Study
Quantitative Analysis of Selected Bone Parameters

Science Discipline
Musculoskeletal

Investigator	Institute
E.R. Morey-Holton	NASA-Ames Research Center

Co-Investigator(s)	Institute
Baylink, D.J.	VA Hospital, Seattle

Research Subject(s)
Rattus norvegicus (Wistar Rat)

12 Flight Male

Ground-Based Controls
12 Vivarium, 12 Synchronous

Key Flight Hardware
Cosmos 782 Russian Hardware Suite

More Information
Mission p. 126-32; Publications p. 422; Hardware p. 455-6

Objectives/Hypothesis
If bones are formed in relation to gravitational stresses, one would anticipate that prolonged recumbency and/or prolonged weightlessness would be associated with hypercalciuria, bone demineralization, and osteoporosis. To better understand the effect of space flight on bone, parameters including formation and mineralization, resorption, length, density and pore size distribution, and bone mechanical properties were studied in rats both immediately postflight and at 25 days postflight.

Approach or Method
Bone density and pore size distribution were measured by mercury porosimetry in the left humerus, while humerus mechanical properties were evaluated with a standard torsion test machine. Bone formation, mineralization, and resorption rates were determined by quantitative histological techniques using the left tibia, while osteoblastic and osteoclastic cell populations were determined from the right. Length measurements were made with calipers, and correlation, regression, and covariance analyses were made by means of computer programs based on standard statistical methods.

Results
Space flight had little effect on the bone porosity parameters measured, while the flight and synchronous animals (compared to viarium controls) did show a significant decrease in bone density immediately postflight. The most striking effects were those on bone formation; all parameters investigated in the flight animals immediately after flight were significantly decreased from both vivarium and synchronous controls. An arrest line was found at both the endosteum and the periosteum of flight animals suggesting that a complete cessation of bone growth occurred during the flight. By 25 days postflight, flight animals showed a significant increase in formation, suggesting that a rebound in bone formation had occurred following flight.

Title of Study

The Morphogenetic Responses of Cultured Totipotent Cells of Carrot at Zero Gravity

Science Discipline

Plant Biology

Investigator	Institute
F.C. Steward	State University of New York

Co-Investigator(s)	Institute
Krikorian, A.D.	State University of New York

Research Subject(s)

Daucus carota (Carrot)

54 ml Flight, 54 ml Centrifuged Cultured Cells

Ground-Based Controls

216 ml Laboratory, 216 ml Laboratory Centrifuged, 54 ml Synchronous, 54 ml Centrifuged Cultured Cells

Key Flight Hardware

Carrot Tissue Containers: Embryoid Container; Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 423; Hardware p. 455-6, 476-7

Objectives/Hypothesis

Free cultured carrot cells can develop like zygotic embryos and can initiate the complex growing regions that produce organs (shoots and roots) independently of the normal environment of the fertilized egg. The principal objective of this experiment was to test whether cells of a higher plant, such as the carrot, could develop normally under space flight conditions and emulate their known ability on Earth to multiply and develop, forming organs, embryoids, and normal plantlets.

Approach or Method

Carrot cells pregrown in liquid suspension cultures were carried in petri dishes encased in special flight canisters and exposed to weightless conditions and rotation in an onboard 1 g centrifuge. The petri dishes contained actively growing cultured cells, all of which were, by filtration through graded sieves, less than 74 µm in size; these cells were distributed in thin layers in an agar culture medium which allowed them to grow heterotrophically in darkness. Postflight, representative samples of different developmental stages were obtained for photography and microscopic examination, and compared to similarly treated ground controls.

Results

The treatments did not produce significantly different proportions of embryos at the various stages of development into which they were classified. Where embryos were larger, their increased size or complexity was in the length of a primary root and in the development of hypocotyls. Shoot development, however, tended to be arrested. Nevertheless, the leaf primordia and shoot apices had become sufficiently established in both flight groups; so when the embryos were exposed to normal earth gravity and to light, their shoots developed rapidly into plantlets. The results seem to indicate that totipotent somatic cells can undergo morphogenesis to produce viable and fully competent embryos in space, apparently as effectively as on Earth.

Title of Study

Response of Crown Gall Tissue to the Space Environment: Tumor Development and Anatomy

Science Discipline

Plant Biology

Investigator	Institute
R. Baker	Colorado State University

Co-Investigator(s)	Institute
Baker, B.L.	Colorado State University
Elliot, L.	Colorado State University

Research Subject(s)

Daucus carota (Carrot) inoculated w/*Agrobacterium tumefaciens*

12 Flight Disks; 12 Flight Centrifuged

Ground-Based Controls

Synchronous; Synchronous Centrifuged

Key Flight Hardware

Carrot Tissue Containers: Tumor Growth Container I

More Information

Mission p. 126-32; Publications p. 423; Hardware p. 476-7

Objectives/Hypothesis

The crown system has been suggested as a model to study the long-term effects of weightlessness on biological systems. Earlier studies show that tumors induced by inoculating cut surfaces of carrot disks with bacterium cells were significantly larger when gravity compensated on clinostats than those developed at 1 g. This study compared tumors developed in the space environment with Earth-based controls.

Approach or Method

Carrots were cross-sectioned and placed aseptically in flight canisters. The upper surfaces of the sections were inoculated with bacterial suspensions (1 $x10^{-8}$ cells/ml) of *Agrobacterium tumefaciens*. The inoculated disks in the canisters were incubated at 25°C for 72 hours to allow initiation of tumors. Canisters were exposed to the weightless conditions of the space environment and to the effects of the on-board centrifuge. Synchronous controls were maintained at both NASA-Ames and in the USSR. Tumors were excised from frozen tissue, weighed, and histologically examined.

Results

Larger (statistically significant) crown gall tumors developed on flight-centrifuged disks than on those exposed only to microgravity. The reaction was opposite to that predicted from previous Earth-based gravity (non)compensated experiments. It is possible that more disks in the weightless treatment were nonresponsive to generation of galls than those on the centrifuge, but plots of individual tumor weights from each disk appear to eliminate this possibility. An increase in radius of the meristemic rings of growth centers in these teratoma type galls was observed, however, for tissues generated in the weightless (flight) and gravity-compensated (ground) conditions. In this respect, results obtained using a clinostat were similar to those observed in tissues developed in microgravity.

Title of Study

Response of Crown Gall Tissue to the Space Environment: Residual Carbohydrates in Supporting Tissue

Science Discipline

Plant Biology

Investigator	Institute
J.E. Hendrix	Colorado State University

Co-Investigator(s)	Institute
Baker, B.L.	Colorado State University

Research Subject(s)

Daucus carota (Carrot) inoculated w/*Agrobacterium tumefaciens*

12 Flight Disks; 12 Flight Centrifuged

Ground-Based Controls

Synchronous; Synchronous Centrifuged; Vertical Rotated; Vertical Stationary; Horizontal Rotated; Horizontal Stationary

Key Flight Hardware

Carrot Tissue Containers: Tumor Growth Container I

More Information

Mission p. 126-32; Publications p. 423; Hardware p. 476-7

Objectives/Hypothesis

A previous study had shown that plant tissue which is gravity compensated on a clinostat has a greater rate of respiration than similar tissue exposed to the normal gravitational environment. This experiment attempts to determine whether this response also occurs in weightlessness. Since it would not be possible to study gas exchange under such conditions, this study instead examines the depletion of carbohydrate reserve as a possible measure of respiration.

Approach or Method

Amounts of amylose, sucrose, and glucose were determined in crown gall tissue in flight and flight-centrifuged (at 1 g) disks, and in comparable control disks. Upon return of flight material, frozen disks and control non-flight disks were lyophilized. Each dried disk was macerated using a mortar and a pestle. From each disc, two samples (approximately 50 mg) of known size were suspended in 80% ethanol, centrifuged, and tested for the appropriate carbohydrates. It should be noted that this study was initiated late in the program as an effort to study differences in respiration and to use all material that was flown.

Results

Both amylose and sucrose decreased in concentration while in the flight environment; however, there was a marked increase in the concentration of glucose. There was no detectable difference between the tissue subjected to the weightless or the flight centrifuged conditions. Since cells of plant tissues must remain turgid to remain healthy, they must adjust their osmotic potential in the face of environmental water stress. The data suggest that water stress was the overriding environmental factor inducing these tissue pieces to increase the proportion of small molecules in their cells, thus permitting them to obtain water, or retain water within their environment.

Title of Study

Response of Crown Gall Tissue to the Space Environment: Glutamine Synthetase Activity

Science Discipline

Plant Biology

Investigator	Institute
S.J. Kleinschuster	Colorado State University

Co-Investigator(s)	Institute
Mahon, K.	Colorado State University

Research Subject(s)

Daucus carota (Carrot) inoculated w/*Agrobacterium tumefaciens*

12 Flight Disks; 12 Flight Centrifuged

Ground-Based Controls

Synchronous; Synchronous Centrifuged; Vertical Rotated; Vertical Stationary; Horizontal Rotated; Horizontal Stationary; CSU Controls

Key Flight Hardware

Carrot Tissue Containers: Tumor Growth Container I

More Information

Mission p. 126-32; Publications p. 423; Hardware p. 476-7

Objectives/Hypothesis

In plants, glutamine synthetase (GS) is the enzyme associated with seeds and relatively undifferentiated embryonic activity. It was of interest, therefore, to determine if the specific activity of this enzyme would be affected by gravity compensation or weightlessness in crown gall tumor tissue. The data obtained would serve as an indicator not only of the comparative differences between normal and pathological material, but also whether gravity-compensation is comparable to weightlessness.

Approach or Method

Upper sections of carrots were cross-sectioned and inoculated with bacterial suspensions (1×10^{-8} cells/ml) of *Agrobacterium tumefaciens* Upon arrival, flight, and similarly treated control material, were weighed, frozen, lyophilized, and stored at -20 °C until assayed. Assays for GS specific activity depended on the gamma-glutamyl-transferase properties of the enzyme and were performed by a sodium arsenate modification of the D. Rudnick et al. method. The specific activity was calculated as the number of micromoles of gamma-glutamyl-hydroxymate produced per hour, per mg protein.

Results

There was a 100% difference in GS specific activity between the flight-weightless and flight-centrifuged material. At no time did the specific activity of the flight material or ground controls approach the activity of normal carrot tissue, and in all cases the activity of the rotated flight material was much lower than stationary controls. While the reasons for these differences are not apparent, a lack of cellular differentiation or hyperplasia of the cambial zone appears to be a characteristic of compensated tumors. GS activity could be expected to be a metabolic participant in neoplasmic activity. The data also indicate that gravity-compensation and true weightlessness, with respect to GS activity, are largely comparable.

Title of Study

Responses to Crown Gall Tissue to the Space Environment: Isozyme Patterns

Science Discipline

Plant Biology

Investigator

P. Hanchey

Institute

Colorado State University

Co-Investigator(s)

none

Institute

Research Subject(s)

Daucus carota (Carrot) inoculated w/*Agrobacterium tumefaciens*

12 Flight Disks; 12 Flight Centrifuged

Ground-Based Controls

Synchronous; Synchronous Centrifuged; Vertical Rotated; Vertical Stationary; Horizontal Rotated; Horizontal Stationary; CSU Controls

Key Flight Hardware

Carrot Tissue Containers: Tumor Growth Container I

More Information

Mission p. 126-32; Publications p. 423-4; Hardware p. 476-7

Objectives/Hypothesis

Clinostats have been used to simulate conditions of zero gravity. Carrot crown gall tumors were reportedly larger with respect to both fresh and dry weights when grown under gravity-compensated (horizontally rotated) conditions on a clinostat. It has also been shown that such tumors display a peroxidase zymogram which differs from that of vertically rotated or stationary controls. This experiment compares peroxidase zymograms between tumor tissue grown in space and that grown on land-based clinostats.

Approach or Method

Carrots were cross-sectioned and placed aseptically, using gnotobiotic techniques, in flight canisters. The upper surfaces of the sections were inoculated with *Agrobacterium tumefaciens*. The following treatments were studied: 1) flight weightless and flight centrifuged (to simulate 1 g) and 2) ground controls clinostat-horizontally rotated (gravity compensated) and horizontal stationary. Peroxidase isozymes were visualized with benzidine. Sufficient material was available for only one extraction and three separate electrophoretic runs. As the results were not identical on each run, an "average summary" was presented.

Results

Only five major bands of peroxidase isozymes were detected in the study, the activity of each band dependent upon the conditions under which the tumors were grown. Both the flight weightless tissue and the clinostat gravity-compensated tissue had a band at the third position which stained intensely. The two treatments were not identical, however, as the gravity-compensated material also contained an isoenzyme with intense activity at position one. The results show both a clear similarity and a clear difference between true weightless and simulated weightless treatments, with similar results apparent between the flight centrifuged and horizontal stationary groups.

Title of Study

HZE-Particle Dosimetry

Science Discipline

Radiation/Environmental Health

Investigator	Institute
E.V. Benton	University of San Francisco

Co-Investigator(s)	Institute
Peterson, D.D.	University of San Francisco
Tran, M.	University of San Francisco

Research Subject(s)

Not Applicable

Ground-Based Controls

Not Applicable

Key Flight Hardware

Radiation Detectors: Plastic Nuclear Track Detectors (PNTD)

More Information

Mission p. 126-32; Publications p. 424; Hardware p. 524-5

Objectives/Hypothesis

This experiment was designed to measure the high-LET particle radiation aboard the Cosmos satellite. One of the specific objectives of this experiment was to determine the number of heavy particles with charge of Z 20 stopping in a one cubic centimeter volume. This information was necessary in order to assess the feasibility of performing U.S. experiments concerning heavy particle track effects in rodent brains aboard future U.S.S.R. Cosmos satellite flights.

Approach or Method

Measurement of the high-LET particle radiation was made with plastic nuclear track detectors. These plastics, cellulose nitrate (CN) and Lexan polycarbonate, can detect a minimum LET value of ~100 keV/µm tissue. Thin detectors measured high-LET particle flux and integral LET spectrum, while a thick detector stack measured the charge spectrum. Scanning and measurement of tracks in plastic films was done with high-resolution optical microscopes. For analysis, measurement of particle LET and change in LET with range were sufficient, along with calibration data, to determine particle atomic number.

Results

The average flux of 4.05 ± 0.70 particles cm^{-2} d^{-1} inside Cosmos 782 was 21% larger than the flux recorded for Skylab-4 astronauts, an expected result primarily due to the higher inclination of orbit. Differences in particle flux values within sets of detectors reflect shielding distribution variances. A layer of CN plastic positioned at the center of the thick stack registered fluence and flux values, respectively, of 67.5 particles cm^{-2} and 3.46 particles cm^{-2} d^{-1}, a value 14.6% lower than the average flux measured by the thin dosimeters. The number of particles with Z 20 stopping per unit volume obtained was 0.9 cm^{-3}.

Title of Study

Cosmic Ray Effect on the Eyes of Rats Flown on Cosmos 782

Science Discipline

Radiation/Environmental Health

Investigator	Institute
D.E. Philpott	NASA-Ames Research Center

Co-Investigator(s)	Institute
Corbett, R.	NASA-Ames Research Center
Sapp, W.	Tuskegee Institute
Savik, L.F.	Institute of Biomedical Problems
Turnbill, C.	NASA-Ames Research Center
Klein, G.	Bruce Lyon Research Laboratory
Harrison, G.	NASA-Ames Research Center
Black, S.	NASA-Ames Research Center
Leaffer, D.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

12 Flight Male

Ground-Based Controls

12 Vivarium, 12 Synchronous; Neon/Argon Irradiated Controls

Key Flight Hardware

Cosmos 782 Russian Hardware Suite; Radiation Detectors: Plastic Nuclear Track Detector (PNTD)

More Information

Mission p. 126-32; Publications p. 424; Hardware p. 455-6, 524-5

Objectives/Hypothesis

A prediction was made in 1952 by C.A. Tobias that "light flashes" would be seen by dark-adapted persons in high flying aircraft and during space flight, as cosmic rays passed through and actuated the photoreceptors of the retina. Cellular damage in the rod free area of the fovea, the area of sharpest vision, could become a severe problem by limiting vision in space travelers. This experiment attempts to further data in the area of long-term, low-dose ocular responses.

Approach or Method

The eyes from six rats were fixed immediately after flight and 25 days postflight, and compared to eyes exposed to 1,000 rads of neon and argon. Sections were cut for electron microscopy for routine examination or whenever light microscopy indicated areas of interest. The outer nuclear layer was examined for radiation changes because these nuclei control the synthesis of the outer segments. Here, any interference in synthesis would be reflected by an alteration in morphology. Radiation detectors were placed aboard the spacecraft to obtain the average flux and atomic number of cosmic ray particles (see experiment C782-9).

Results

Most of the flight eye tissue was normal, indicating space flight for this duration would be safe for humans. Necrotic nuclei were found in the outer nuclear layer and channels were located in the outer segment. Macrophages were seen between the pigment layer and the outer segment. Analysis of the eyes fixed at 25 days postflight suggested some recovery. Light flashes and damage from cosmic rays appear to be created by cosmic ray traversal of the outer segments while pathology, when it occurs, is quite possibly from interaction with some part of the nucleus; nevertheless, direct interaction on the cellular components could also have occurred.

Title of Study

Absence of Gastric Ulceration in Rats After Flight on the Cosmos 782

Science Discipline

Regulatory Physiology

Investigator	Institute
P.A. Brown	NASA-Ames Research Center

Co-Investigator(s)	Institute
Vernikos-Danellis, J.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

6 Flight Male

Ground-Based Controls

6 Vivarium, 6 Synchronous

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 424; Hardware p. 455-6

Objectives/Hypothesis

A variety of environmental stressors can be shown to produce gastric ulceration in rats. Several converging lines of research have shown that endogenous histamine plays an essential role in stress-produced gastric ulceration. It has been demonstrated, as well, that the mechanism specifically involves the H2 receptor for histamine. Whether the actual stresses associated with a long-term space flight are sufficient to produce gastric ulceration in rats is uncertain, and the focus of this study.

Approach or Method

Stomachs from the flight animals were compared with stomachs removed from animals in synchronous and vivarium control groups. The stomachs were examined microscopically for gastric ulceration using the following classification: a) petechial ulcers: minute superficial erosions involving only the mucosa; b) punctate ulcers: discrete punched out ulcerations measuring at least 1 mm; and c) longitudinal ulcers: continuous linear ulcerations larger than 1 mm. Tissue for histological examination was taken from the rumen, corpus, and antrum; hematoxylin and eosin sections were examined microscopically for evidence of superficial erosion of the mucosa.

Results

None of the animals examined from the flight or control groups evidenced gastric ulcers or pronounced mucosal erosion, a not unexpected result. In conjunction with other experiments, most of the animals in flight and synchronous groups were maintained on the antibiotic Declomycin. A broad spectrum of antibiotics can result in a deficiency of pyridoxal phosphate, a required co-factor in the biosynthesis of histamine. A histamine depletion could afford protection against experimental ulceration, as would the six-hour feeding intervals, as a minimum of 24 hours of food deprivation is usually required to produce stress ulcers in rats. Possibly, during the initial phase of the flight the animals did ulcerate, but recovered prior to return.

Title of Study

Alterations in Erythrocyte Survival Parameters in Rats After 19.5 Days Aboard Cosmos 782

Science Discipline

Regulatory Physiology

Investigator	Institute
H.A. Leon	NASA-Ames Research Center

Co-Investigator(s)	Institute
Landaw, S.A.	Syracuse VA Hospital
Cummins, J.	Northrop Services, Inc.
Serova, L.V.	Institute of Biomedical Problems
Chelnaya, N.A.	Institute of Biomedical Problems
Deryagina, S.N.	Institute of Biomedical Problems
Potapova, G.M.	Institute of Biomedical Problems
Churakova, A.V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

6 Flight	Male

Ground-Based Controls

6 Vivarium

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 424; Hardware p. 455-6

Objectives/Hypothesis

The results of the Skylab flights demonstrate that prolonged weightlessness causes a significant decrease in red cell mass of astronauts which is not related to oxygen partial pressure. The objective of this experiment was to determine if the complex factors associated with relatively prolonged space flight interact to alter survival parameters of preformed red blood cells in rats.

Approach or Method

Based on the amount of exhaled carbon-14 labeled carbon monoxide, survival parameters of a cohort of erythrocytes labeled 15.5 days preflight were evaluated upon return from orbit and compared to control rats injected at the same time. Breath samples were taken for three hours at the same time each day to minimize potential circadian fluctuations. The ^{14}CO generated was trapped in ethanolamine/2-Ethoxyethanol and triplicate aliquots were counted by liquid scintillation. The obtained data points were fitted into an equation relating red blood cell survival to ^{14}CO production, using a computer.

Results

Statistical evaluation indicates that all survival parameters were altered by the space flight. The mean potential red blood cell life span, which was 62.4 days in control rats, was decreased to 59.0 days in the flight rats, and random hemolysis was increased three-fold in the flight rats. The measured size of the cohort was decreased, lending further support to the idea that hemolysis was accelerated during some portion of the flight. Factors which might be contributory to these changes include forces associated with launch and re-entry, atmospheric and environmental parameters, diet, radiation, and of course, weightlessness.

Title of Study

Effects of Spaceflight on Plasma and Glandular Concentrations of Pituitary Hormones

Science Discipline

Regulatory Physiology

Investigator	Institute
R.E. Grindeland	NASA-Ames Research Center

Co-Investigator(s)	Institute
Keil, L.C.	NASA-Ames Research Center
Parlow, A.F.	University of California, Los Angeles
Kendall, J.W.	VA Hospital, Portland
Ellis, S.	NASA-Ames Research Center
Geschwind, I.I.	University of California, Davis

Research Subject(s)

Rattus norvegicus (Wistar Rat)

11 Flight Male

Ground-Based Controls

11 Vivarium, 11 Synchronous

Key Flight Hardware

Cosmos 782 Russian Hardware Suite

More Information

Mission p. 126-32; Publications p. 425; Hardware p. 455-6

Objectives/Hypothesis

The important role played by hormones in regulation of metabolic parameters affected by space flight suggests that altered endocrine function may have contributed to other observed metabolic changes. The aims of the present study were to clarify the effects of space flight on pituitary function by measuring plasma and glandular concentrations of pituitary hormones and, where feasible, evaluating the status of the appropriate target tissue.

Approach or Method

At the conclusion of the flight all rats were weighed and inspected. Anterior and posterior-intermediate lobes were collected, weighed, and individually frozen for assays. Plasma and pituitary growth hormone (GH), and prolactin were immunoassayed using GH and prolactin purified in-house as standards. Thyrotropin was assayed by a double antibody method, and luteinizing and follicle stimulating hormones by procedures employing NIAMDD rat standards. Adrenocorticotropic hormone (ACTH) was immunoassayed using the 3rd International Standard (porcine). Vasopressin was measured by a radioimmunoassay procedure and melanocyte stimulating hormone (MSH) by the bioassay method.

Results

Although of modest extent, some perturbations of endocrine function were found in this investigation. The low plasma GH titers of flight animals either reflects the unusual sampling conditions at recovery or the effects of weightlessness. The larger adrenals of flight rats suggests they were secreting increased quantities of corticosterone over a significant part of the flight, which may have contributed to the smaller flight body weights by its protein catabolic effect. The adrenal hypertrophy of flight rats suggests these animals were secreting more ACTH and corticosterone during flight. There were no changes in either pituitary or plasma MSH suggesting that either the type or degree of stress was not adequate to stimulate MSH secretion.

Title of Study

Effect of Weightlessness and Centrifugation (1xG) on Erythrocyte Survival in Rats Subjected to Prolonged Spaceflight

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
H.A. Leon	NASA-Ames Research Center

Co-Investigator(s)	Institute
Landaw, S.A.	VA Hospital, Syracuse
Serova, L.V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight, 5 Centrifuged Male

Ground-Based Controls

6 Vivarium, 5 Synchronous, 5 Centrifuged

Key Flight Hardware

Cosmos 936 Russian Hardware Suite

More Information

Mission p. 133-8; Publications p. 425; Hardware p. 455-6

Objectives/Hypothesis

With few exceptions, the loss of a variable quantity of red blood cell (RBC) mass has been a consistent finding in humans subjected to space flight. Past data suggest that mechanisms other than oxygen-induced hemolysis must be operative to cause this decrease in RBC mass. Analysis of Cosmos 782 data showed that random hemolysis was increased three-fold in the flight rats and the mean potential life span was decreased about 5%. The present experiment was undertaken to verify the alterations seen in Cosmos 782 and to ascertain if the alterations could be attenuated by artificial gravity via an onboard centrifuge.

Approach or Method

Five rats were subjected to near weightlessness space flight and five rats were subjected to a 1 g force via an onboard centrifuge. Comparisons were made to ground-based vivarium, and synchronous stationary and centrifuged controls. Erythrocyte hemolysis and life span were evaluated by quantification of radioactive carbon monoxide exhaled in breath, which arises from the breakdown of the previously 2-^{14}C glycine labeled hemoglobin.

Results

Considering only the output of ^{14}CO during the first three days postflight, radioactivity was 60% higher in the flight-weightless than in the flight-centrifuged group. The mean, overall, RBC life-span was significantly shortened in the latter group as a result of increased hemolysis, a difference even more pronounced if the one rat that suffered measurable injury is excluded from the data. Changes in hemolysis are also reflected in the portion of RBCs dying of senescence. The results support previous findings, wherein hemolysis was found to increase as a result of space flight. Unrelated to exogenous factors, this change appears specific to weightlessness, since it was attenuated by artificial gravity created by inflight centrifugation. A possible initiator of the hemolysis is a cephalad fluid shift and subsequent hemoconcentration caused by the weightlessness.

Title of Study
Quantitative Analysis of Selected Bone Parameters

Science Discipline
Musculoskeletal

Investigator	Institute
E.R. Morey-Holton	NASA-Ames Research Center

Co-Investigator(s)	Institute
Turner, R.T.	American Lake VA Medical Center
Baylink, D.J.	American Lake VA Medical Center

Objectives/Hypothesis
Changes in calcium homeostasis present a potential problem during prolonged space flight. Since mechanical forces imposed by muscle utilization and gravity influence bone turnover, prolonged recumbency and/or prolonged weightlessness with continuous hypercalciuria and bone loss could ultimately result in osteoporosis. To better understand the effect of space flight and gravity on bone, the following parameters: formation and mineralization, resorption, length, density and pore size distribution, and mechanical properties, were studied in stationary and centrifuged space-flown rats both immediately following recovery and 25 days postflight.

Approach or Method
Density and pore size distribution were measured in the left femur by mercury porosimetry; mechanical parameters were evaluated with a standard torsion test machine. The rate of bone formation and resorption was determined in the left tibia by quantitative histological techniques; in addition, osteoblast and osteoclast cell number was determined.

Research Subject(s)
Rattus norvegicus (Wistar Rat)

5 Flight, 5 Centrifuged Male

Ground-Based Controls
12 Basal, 10 Vivarium, 4 Synchronous, 5 Centrifuged

Key Flight Hardware
Cosmos 936 Russian Hardware Suite

More Information
Mission p. 133-8; Publications p. 425; Hardware p. 455-6

Results
The data obtained demonstrate that: no gross change in endosteal bone resorption occurs during flight or postflight; mean periosteal bone formation rate decreases about 45% and is not corrected by centrifugation; the decrease in formation rate may be due, in part, to a cessation of bone formation which occurs sometime after the eleventh day of flight and continues until the second postflight day; although centrifugation did not correct the defect in periosteal bone formation rate during flight, it appears to hasten the recovery following flight; femur stiffness decreases about 30%; and centrifugation did correct the defect in bone mechanical properties. All perturbations normalized by 25 days postflight. The reduction of mechanical stress is probably not sufficient to account for the decreased rate of bone formation since a comparable decrease occurred in the flight centrifuged rats. However, the mechanical strength of the femur was not reduced in these animals, and bone formation was apparently reinitiated immediately upon recovery in centrifuged rats, whereas it was delayed two to three days in flight rats.

Title of Study

Quantitative Analysis of Selected Bone Parameters: Formation of Ectopic Bone in Implanted Matrices

Science Discipline

Musculoskeletal

Investigator	Institute
D.J. Baylink	American Lake VA Medical Center

Co-Investigator(s)	Institute
Shvets, V.N.	Institute of Biomedical Problems
Turner, R.T.	American Lake VA Medical Center
Holton, E.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 936 Russian Hardware Suite

More Information

Mission p. 133-8; Publications p. 425; Hardware p. 455-6

Objectives/Hypothesis

Undenatured bone matrix, demineralized and lypholized, induces bone formation when implanted in muscle or fascia of host animals. This model was employed by Soviet scientists to evaluate the effects of space flight on bone formation in implanted matrices. Approximately half the implanted matrices recovered from basal, synchronous, vivarium control, and flight groups of rats were sent to the U.S. for independent evaluation. These were accompanied by samples of unimplanted bone matrix.

Approach or Method

Representative samples of ectopic bone recovered from each host rat were dried, weighed, and digested in 6N HCL. Calcium content was determined on an aliquot by atomic absorption spectrophotometry and µg Ca/mg dry weight of sample was calculated. Specimens were prepared by a method which has been developed to preserve enzyme activity in mineralized bone, thus permitting the identification of osteoclasts as well as osteoblasts. Specimens were cut into two to four segments and embedded for sagittal sectioning, producing 57 tissue blocks, each containing from one to three segments of the specimen. Sections were stained by the Goldner technique and a method intended to differentiate osteoblasts and osteoclasts by taking advantage of the high RNA content of the former and acid phosphatase activity of the latter, and examined microscopically.

Results

A subjective study of slides suggests that the only areas stained green by the Goldner technique are mineralized bone, in contrast to what has been found in rat and human bone, and in unimplanted bone matrix. In these, all "mature," or once mineralized matrix stains green even after being completely demineralized, and only newly formed osteoid stains red. If that were the case in the implanted matrices, all the old, implanted matrix except its normal borders of osteoid would be stained green as well as the mineralized bone formed during the time the matrix was implanted in the host rat. One would then expect the red-stained area to be limited to the osteoid of the original matrix and the osteoid formed during the period of implantation which had not yet mineralized. Instead, it seems (but is not yet proven) that all the old matrix, whether once mineralized or not, is stained red. This suggests that a change occurred in the implanted matrix which could not be demonstrated in the specimens of the unimplanted matrix, reflected in a change of its tinctorial properties, and deserves further study.

Title of Study
Spaceflight Effects on Muscle Fibers

Science Discipline
Musculoskeletal

Investigator	Institute
K.R. Castleman	Jet Propulsion Laboratory

Co-Investigator(s)	Institute
Chui, L.A.	USC School of Medicine
Van Der Meulen, J.P.	USC School of Medicine

Research Subject(s)
Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls
5 Vivarium, 5 Synchronous

Key Flight Hardware
Cosmos 936 Russian Hardware Suite

More Information
Mission p. 133-8; Publications p. 426; Hardware p. 455-6

Objectives/Hypothesis
Whether a muscle fiber employs an oxidative or glycolytic energy mechanism is not immutably fixed, but can be influenced by external factors. Since space flight drastically alters the stimulus patterns to which skeletal muscle is exposed, it is relevant to investigate the changes which take place, not only in the muscle fiber size, but also in the energy mechanism. Rather than sampling each muscle only at a few positions along its length, this experiment seeks a quantitative total ascertainment of fiber size, number, and type.

Approach or Method
Muscle fiber size and type distribution were studied in the extensor digitorum longus (EDL) muscle of space-flown rats and controls, using histochemical preparation techniques and computer image analysis to quantify the space-flight-induced changes in muscle fiber size, number, and energy metabolism. The computer program produces a scatter plot showing how the fibers are distributed in diameter and optical density.

Results
Average fiber diameter was largest in the vivarium control animals and smallest in the flight animals. Flight muscles appeared to be shorter than those of other groups. If this length difference is not an artifact of dissection, it could be the result of chronic extension of the foot and/or toes during space flight. Fiber number showed no significant difference. The "slow" fiber percentage was quite variable, and no statistically significant fiber type conversion was noted. There were no major cytoarchitectural changes, and necrotic changes and "moth eaten" fibers were not seen. The grouped grand mean fiber diameters show 17% and 7% reductions for the flight and synchronous groups, respectively, when compared to the vivarium group, strongly supporting the contention that hypogravity aggravates the atrophic effects of hypokinesis. While reduced activity may be the major cause of fiber atrophy in space flight, other factors may contribute. For example, the stress of negotiating the microgravity environment could produce an ACTH-cortisol response, a possible contributor to reduced fiber size.

Title of Study

Space Radiation Dosimetry On Board Cosmos 936

Science Discipline

Radiation/Environmental Health

Investigator	Institute
E.V. Benton	University of San Francisco

Co-Investigator(s)	Institute
Cassou, R.	University of San Francisco
Frank, A.	University of San Francisco
Peterson, D.D.	University of San Francisco
Henke, R.P.	University of San Francisco

Research Subject(s)

Not Applicable

Ground-Based Controls

Not Applicable

Key Flight Hardware

Radiation Detectors: Cosmos 936 Radiation Detector Packets

More Information

Mission p. 133-8; Publications p. 426; Hardware p. 526-7

Objectives/Hypothesis

Life systems in space experience a unique and complex environment, including radiation, which presents hazards that may impair normal physiological processes and thereby limit their natural functions. The radiation dosimetry experiments were designed mainly to determine physical parameters of the different components of the radiation in space. The Cosmos 936 study included a comparison of results between U.S. and U.S.S.R. investigators with the objective to elucidate results from the Cosmos 782 mission which contained an unexplained difference in HZE (high-energy ionized particle) flux values measured by investigators of the different countries.

Approach or Method

Results were derived from measurements made in a variety of passive radiation detectors, including plastic nuclear track detectors (PNTDs), fission foil detectors, thermoluminescent dosimeters (TLDs), and nuclear emulsions. Measurements were made of HZE particles, neutrons, protons, and the total radiation dose.

Results

The mean observed HZE particle flux, as measured in cellulose nitrate PNTDs, was 1.75 cm^{-2} d^{-1} (±20%), compared with 4.05 cm^{-2} d^{-1} (±17%) on Cosmos 782. The charge spectrum of HZE particles was measured in the region 6 £ Z £ 18. The fluences of thermal neutrons (<0.3 eV), resonance neutrons (0.3 eV-1 MeV) and high energy neutrons (>1 Mev) were, respectively, 3.64 x 10^{-5} cm^{-2} (±20%), 9.5 x 10^{-5} cm^{-2} (-30% to +50%), and 2.1 x 10^{-6} cm^{-2}. The total dose measured in TLD chips was 424 mrad (±9%) and 523 mrad (11%). The mean tissue equivalent proton ender density measured in nuclear emulsions was 2.72 x 10^{-5} cm^{-3} tissue. The physical parameters reported here help specify important dosimetric information required to assess the potential radiation hazards to life systems in space.

Title of Study

Cosmic Ray Effects on the Eyes of Stationary and Centrifuged Rats Flown on Cosmos 936

Science Discipline

Radiation/Environmental Health

Investigator	Institute
D.E. Philpott	NASA-Ames Research Center

Co-Investigator(s)	Institute
Corbett, R.	NASA-Ames Research Center
Turnbill, C.	NASA-Ames Research Center
Black, S.	NASA-Ames Research Center
Dayhoff, D.	NASA-Ames Research Center
McGourty, J.	NASA-Ames Research Center
Lee, R.	NASA-Ames Research Center
Harrison, G.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight, 5 Flight Centrifuged — Male

Ground-Based Controls

5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 936 Russian Hardware Suite

More Information

Mission p. 133-8; Publications p. 426; Hardware p. 455-6

Objectives/Hypothesis

The site of sharpest vision is located in the rod-free area of the fovea, the tiny central area of the macula. Cellular damage in this area, about 26 µm diameter in humans, could become a severe problem by limiting vision in space travelers. It is known that a short term flight causes damage in the retinas of mice and rats. In longer space flights, long term, low dosage radiation could cause lens changes, leading to cataracts. Although data are lacking in this area of long-term, low dose response, the possibility of extended flights makes such information vital.

Approach or Method

Radiation dosimeters were placed in the biosatellite to obtain an average flux and atomic number of the cosmic ray particles. Photomontages were constructed and large retinal areas from flight and control eyes were compared to each other. Some micrographs of the outer nuclear layer of the retina (ONL) from an eye in each group were put on a Ladd digitizer, and the cells were counted and measured. Averages for population density, width of the ONL, and nuclear volume were computed for flight stationary, flight centrifuge, and ground controls.

Results

The flux of HZE particles indicated an average of 35 particles/cm^{-2} for the 18.5 day flight in the areas where the dosimeters were placed. No differences were noted when comparing flight-weightless to flight-centrifuged samples. Affected cells in the outer nuclear layer, where synthesis of the outer segment takes place, showed swelling, clearing of the cytoplasm, and disruption of the membranes. The abnormal assembly of the membranes could be a consequence of altered DNA. Preliminary results using the digitizer indicated an increase in cell size after radiation, a narrowing of the ONL in flight eyes, and a decrease in the number of cells in the outer nuclear layer. Since active synthesis in the ONL magnifies any pathological insult to ONL cells, the vesiculated membranes found in the rods may be due to improper synthesis of membrane material. Cell necrosis in the retina seems to follow the same pattern after exposure to HZE both on the ground and in space. Following cell enlargement, cellular collapse occurs, which may be due to membrane dysfunction as active transport ceases.

Title of Study

Effects of Weightlessness on the Genetic and Aging Process of *Drosophila melanogaster*

Science Discipline

Cell/Developmental Biology

Investigator	Institute
J. Miquel	NASA-Ames Research Center

Co-Investigator(s)	Institute
Philpott, D.E.	NASA-Ames Research Center

Research Subject(s)

Drosophila melanogaster (Fruit Fly)

260 Flight (approximation)

Ground-Based Controls

260 Synchronous (approximation)

Key Flight Hardware

Cosmos 936 Russian Hardware Suite

More Information

Mission p. 133-8; Publications p. 426-7; Hardware p. 455-6

Objectives/Hypothesis

The main purpose of the U.S.S.R. portion of this experiment was to study the genetic effects of near-weightlessness, while the U.S. contribution was concerned with the developmental and aging process. This investigation was intended to be a follow-up to the *Drosophila* experiment flown previously on Cosmos 782, which suggested that the development of *Drosophila* was not appreciably affected by the lack of gravity.

Approach or Method

Two age groups of mature flies (7 and 26 days at launch) were used in order to compare the effects of microgravity on insects which were at the peak of their vitality, with others already shown to exhibit senescent loss of vigor and tissue disorganization. Investigations included: determination of vitality, as expressed in negative geotaxis and mating; study of the external morphology using a scanning electron microscope; investigation of age-associated changes in the muscle and other tissues by transmission electron microscopy on material fixed in glutaraldehyde; and life span determination on seventy flies from Cosmos-flown and synchronous populations.

Results

The transmission electron microscopic study demonstrated the presence of normal mitochondria both in flies which developed in space and in those which were exposed to microgravity as young and middle aged imagoes. On the other hand, the amount of glycogen granules in the wing were strikingly lower in the Cosmos-flown young flies than in their ground controls. Regarding embryonic development, these findings are in agreement with previous research and observations on Cosmos 782, suggesting that near-weightlessness does not seriously interfere with the developmental processes of *Drosophila*. However, the reduced vitality and the short life span manifested by the flies which were exposed to hypogravity during the first days of their imaginal life suggests that the aging process may be accelerated during space flight. These effects may be similar to those of other life-shortening environmental parameters, such as moderately raised oxygen tensions and high ambient temperature.

Title of Study

The Effects of Spaceflight on Some Liver Enzymes Concerned with Carbohydrate and Lipid Metabolism in the Rat

Science Discipline

Regulatory Physiology

Investigator	Institute
S. Abraham	Bruce Lyon Memorial Research Lab.

Co-Investigator(s)	Institute
Klein, H.P.	NASA-Ames Research Center
Lin, C.Y.	Bruce Lyon Memorial Research Lab.
Volkmann, C.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight, 5 Centrifuged Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Centrifuged

Key Flight Hardware

Cosmos 936 Russian Hardware Suite

More Information

Mission p. 133-8; Publications p. 427; Hardware p. 455-6

Objectives/Hypothesis

During early manned space flights, a specific physiological enigma concerning caloric requirements was noted. While theoretically in the absence of gravitational force less energy should be required for life-sustaining functions, on the initial flights where caloric intake was restricted, a marked inflight loss in body weight resulted. It is important to study a key organ like the liver in order to determine whether any regulative enzymes of carbohydrate and lipid metabolism might have been affected; that is, whether the capabilities of the organ to produce these cellular constituents is, in fact, altered in space flight.

Approach or Method

In the rat liver, the activities of about thirty enzymes concerned with carbohydrate and lipid metabolism were examined according to well-established methods or modifications of currently used techniques. In addition, the levels of glycogen and of the individual fatty acids in hepatic lipids were determined. The livers from rats subjected to near weightlessness space flight and rats subjected to a 1 g force via an onboard centrifuge were compared to appropriate ground-based controls. Several key enzymes of lipid biosynthesis, many of which are known to be regulative, were studied in this experiment, including acetyl-CoA carboxylase, fatty acid synthetase, palmitoyl-CoA synthetase, and stearoyl-CoA desaturase.

Results

In rats sacrificed at recovery, statistically significant decreases in the activity levels of α-glycerol-phosphate acyltransferase, diglyceride acyltransferase, aconitase, and 6-phosphogluconate dehydrogenase were noted in the flight-weightless group versus flight-centrifuged animals. The flight-weightless group also contained, on average, more than twice the amount of glycogen than did flight-centrifuged livers, and a remarkable shift in the ratio of palmitate to palmitoleate was noted. As a possible explanation, it was observed that although glycogen synthetase activity was about the same in all groups, its glycogen phosphorylase activity was significantly less. The observed alterations, particularly those that involved increased glycogen levels and decreased activities of the acyl transferases concerned with lipid synthesis, appear unique to the weightless condition. Most of the enzyme activities, though, did not show any significant differences between weightless and centrifuged rats, and all parameters had returned to normal by 25 days postflight.

Title of Study
Rat and Quail Ontogenesis

Science Discipline
Cell/Developmental Biology

Investigator	Institute
J.R. Keefe	BioSpace Incorporated

Co-Investigator(s)	Institute
none	

Research Subject(s)
Rattus norvegicus (Wistar Rat)
Coturnix coturnix (Quail)
7 Flight Rats (5 Female); 60 Flight Eggs Male/Female

Ground-Based Controls
7 Synchronous Rats; 60 Synchronous Eggs

Key Flight Hardware
Cosmos 1129 Russian Hardware Suite

More Information
Mission p. 139-44; Publications p. 427; Hardware p. 456

Objectives/Hypothesis
The flight of Cosmos 1129 attempted to provide information with respect to potential effects of space flight on mammalian fertilization, implantation, and embryonic development. The principal objectives of this study were: 1) to determine the capability of a selected mammalian species to undertake reproductive processes, including copulation, fertilization, placentation, and embryogenesis during space flight exposure; 2) to separate potential space flight factors from indirect factors due to stress; and 3) to demonstrate the capability of avian embryos to carry out normal embryogenesis during space flight.

Approach or Method
Both flight and synchronous rat groups were provided a dual chambered mating cage. Fertility in test animals was assured by successful preflight breeding. The divider separating male and female rats was removed on the second day of flight. Seventeen days after recovery, flight and control females were laparotomized and the uteri and ovaries photographed. "Triangular implantation sites" and "yellow bodies" (Corpora lutea) were tallied by gross inspection. Two flight females and flight males were mated postflight.

Although all of the quail eggs were adversely impacted by an inflight failure of the incubator humidifier, several embryos were able to progress to a developmental stage equivalent to that of a control ten- to twelve-day embryo. Postflight, representative samples of the dead embryos were fixed in Bouins solution and examined by light microscopy.

Results
None of the flight or synchronous rat females gave birth as a result of breeding that may have occurred during the flight phase of the experiment. Flight males have subsequently sired litters from both vivarium and post-operative flight females. One flight and two synchronous females have since produced viable litters with a normal size and sex ratio. Pups from these litters demonstrate normal morphological development. The basic questions concerning mammalian copulation, insemination, fertilization, implantation, placentation, and embryogenesis still remain unanswered.

Based upon examination of the external features and analyses of the one quail flight embryo received, development under conditions of space flight appeared to be normal. The drop in relative humidity to a level of 23-25% for a period over six days must have led to a dehydration of the eggs and an increase in the fragility of the shell.

Title of Study

Fetal and Neonatal Rat Bone and Joint Development Following In Utero Spaceflight

Science Discipline

Cell/Developmental Biology

Investigator	Institute
E.E. Sabelman	University of California, San Francisco

Co-Investigator(s)	Institute
Holton, E.M.	NASA-Ames Research Center
Arnaud, C.D.	University of California, San Francisco

Research Subject(s)

Rattus norvegicus (Wistar Rat)

7 Flight Rats (2 Male and 5 Female) Male/Female

Ground-Based Controls

7 Synchronous Rats (2 Male and 5 Female)

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 427; Hardware p. 456

Objectives/Hypothesis

The thrust of this study was altered by circumstances from the initial proposal to investigate the effects of prenatal exposure to space flight on rat limb development. Since no litters were born following inflight impregnation, the only specimens were produced by vivarium and postflight pregnancies. An effort was made to measure differences between groups of specimens attributable to maternal housing, diet, or stress, which must be compensated for in future mammalian embryology experiments in space.

Approach or Method

After separation into single limbs, with skin removed to mid-tibia, specimens were superficially examined and macrophotographed at 3x. With input from a microscope and camera, radiographic density was measured using an image analysis system consisting of a camera, a video-digitizer terminal and computer. Data were obtained on maturation of ossification centers, orientation of collagen fibers in the bone, tendon and ligament, joint surface texture and spatial relationships of bones and the hindlimb. A comparison was also conducted between vivarium (standard) and flight-type (Soviet paste) diets.

Results

No overt anatomical abnormalities were noted in domestic or Soviet specimens. Weights of offspring whose dams were fed Soviet diet did not differ significantly until after day fifteen from standard diet controls. In pups less than two days old, tendon and ligament insertions tended to merge with the perichondrium rather than penetrate into underlying cartilage or bone. The texture of the minuscule fibrocartilage was distinct from adjacent ligament, with prominent cell lacunae which could be indicators of states of mechanical stress. Because of unknown degrees of sensitivity of bone and joint maturation of Czech Wistars to such factors as litter size, gestation age, uterine position, or birth order, this data should be gathered for all specimens, in addition to the age and weight at sacrifice. Certainly, environmental parameters to which flight and synchronous control groups were exposed, such as noise, vibration, and possible hypoxia, should be measured during future studies. Computer reconstructions of knee and hip show promise as a means of investigating the etiology of congenital hip dislocation.

Title of Study

Quantitative Analysis of Selected Bone Parameters

Science Discipline

Musculoskeletal

Investigator	Institute
T.J. Wronski	NASA-Ames Research Center

Co-Investigator(s)	Institute
Morey-Holton, E.R.	NASA-Ames Research Center
Cann, C.E.	University of California, San Francisco
Baylink, D.J.	American Lake VA Medical Center
Arnaud, C.D.	University of California, San Francisco
Turner, R.T.	American Lake VA Medical Center
Jee, W.S.S.	University of Utah

Research Subject(s)

Rattus norvegicus (Wistar Rat)

25 Flight Male

Ground-Based Controls

25 Vivarium, 25 Synchronous

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 427; Hardware p. 456

Objectives/Hypothesis

According to previous space flight research, differential effects are noted not only between weight-bearing and non-weight-bearing bones, but also are seen within different regions of the same bone. Therefore, one of the objectives of this study was to determine growth at the periosteum in different regions both in weight-bearing (tibia) and non-weight-bearing (rib) bones. Following both Cosmos 782 and 936, an arrest line was found in all flight rats and was both more distinct and more extensive than in controls. Another objective of this study was to obtain more precise measurements and further define this arrest line.

Approach or Method

The Merz grid was used to quantify the rate of periosteal bone formation in the tibial and humeral diaphysis, and to aid in quantification of the fractional area of trabecular bone and the fractional area of fat in the bone marrow of the proximal tibial metaphysis. Additional cross-sections of the tibial diaphysis were used for chemical characterization of the arrest lines.

Results

The skeletal alterations induced by space flight were determined to be: a reduced rate of periosteal bone formation in the tibial and humeral diaphyses; and a decreased trabecular bone volume and an increased fat content of bone marrow in the proximal tibial metaphysis. Inhibition of periosteal bone formation in the humerus was not as dramatic as in the tibia, probably due to the lower rate of periosteal bone formation in the humerus relative to the tibia. An increased incidence of arrest lines was seen in flight animals. The staining properties of these arrest lines and the demonstration that osteocyte canaliculi rarely pass through them, suggest that they represent a cessation of bone matrix formation followed by reinitiation of bone formation at a later time. The rate of periosteal bone formation in the rib was not significantly decreased during space flight, possibly due to its non-weight-bearing nature; periosteal bone formation rate in the rib may be too low to exhibit a significant change during a relatively short flight. Endosteal bone resorption was not affected markedly by space flight.

Title of Study

Quantitative Analysis of Selected Bone Parameters: Supplemental Report 1: Effects of Weightlessness on Osteoblast

Science Discipline

Musculoskeletal

Investigator	Institute
W.E. Roberts	University of the Pacific

Co-Investigator(s)	Institute
Mozsary, P.G.	University of the Pacific
Morey-Holton, E.R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

15 Flight Male

Ground-Based Controls

15 Vivarium, 15 Synchronous

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 427-8; Hardware p. 456

Objectives/Hypothesis

Marked depression or arrest of bone formation has been associated with space flight and simulated weightlessness. The mechanism of this suppression of osteogenesis is unclear, but probably involves altered induction. Data indicate that nuclear volume frequency distributions are an effective means of assaying preosteoblast differentiation in a population of connective tissue cells. Thus, the objective of this experiment was to determine whether space flight would alter cellular induction in the fibroblast-like cells in the rat periodontal ligament (PDL).

Approach or Method

PDL, the osteogenic interface between tooth and bone, was morphometrically analyzed. The region studied was a 300 µm length of midroot PDL on the medial aspect of the medial root of the maxillary first molars. Volumes for 100 nuclei from throughout the width of the PDL were determined, and frequency distributions of nuclear volume for each group were calculated. Studies were conducted on rats sacrificed at recovery and six and 29 days postflight.

Results

Immediately postflight, PDL width and total cell number were decreased. Frequency distributions of nuclear volume revealed that presumptive preosteoblasts (nuclei 130 μm^{-3}) were particularly depressed. Compared to vivarium controls, frequency distributions of nuclear volume revealed a relative increase in smaller nuclei (£ 80 μm^{-3}) at the expense of these larger nuclei. No significant differences in interzone mean nuclear volumes were observed for the groups sacrificed at six and twenty-nine days postflight. This study suggests that depleted numbers of preosteoblasts may be an important factor in the arrest of bone formation during weightlessness. Data are consistent with either a defect in proliferation and/or differentiation. Additional cell kinetic studies utilizing ^{3}H-thymidine are needed to define the mechanism of this important aerospace problem.

Title of Study

Quantitative Analysis of Selected Bone Parameters: Supplemental Report 2: Bone Elongation Rate and Bone Mass in Metaphysis of Long Bones

Science Discipline

Musculoskeletal

Investigator	Institute
W.S.S. Jee	University of Utah

Co-Investigator(s)	Institute
Kimmel, D.B.	University of Utah
Smith, C.	University of Utah
Dell, R.B.	University of Utah

Research Subject(s)

Rattus norvegicus (Wistar Rat)

15 Flight Male

Ground-Based Controls

15 Vivarium, 15 Synchronous

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 428; Hardware p. 456

Objectives/Hypothesis

The purpose of this study was to determine whether bone elongation rate and bone cell number in the metaphysis of long bones were altered by Cosmos 1129 space flight. An attempt was made to measure the rate of bone elongation directly in the proximal tibial and humeral metaphysis by the use of tetracycline labeling.

Approach or Method

The proximal tibial and humeral metaphysis from groups of animals sacrificed at recovery (R-0) and six (R+6) and twenty-nine days (R+29) postflight was measured using quantitative light microscopic techniques. One section of the proximal humerus of each animal was randomly selected. The following parameters were calculated for each band analyzed in the metaphysis: fractional bone and fractional calcified cartilage volumes; osteoblast, osteoprogenitor cell, and osteoclast nucleus numbers; ratios of osteoblast, osteoprogenitor cell, and osteoclast nuclei to surface area of bone; and fractional fatty marrow volume.

Results

The study demonstrated a reduction in bone and calcified cartilage volume in flight and synchronous animals, in a region of the metaphysis where a maximum of calcified tissues was seen in vivarium controls. This was associated with a decreased number of functional bone cells (osteoblasts and osteoclasts) in both flight and (probably) synchronous groups. It was also clear that the metaphysis had returned to normal by the end of the 29-day recovery period. The fatty marrow volume was increased only in flight groups R-0 and R+6, but was normal in R+29 animals. The decreased amount of bone and calcified cartilage is believed to be the result of a temporarily slowed or arrested production of calcified cartilage as a substrate for bone formation. This would have resulted from slowed bone elongation during flight and synchronous control conditions. Since the synchronous group seemed to show significant changes quite similar to the flight animals, this data indicate that the general stress as well as the flight itself had an effect on the rate of bone elongation.

Title of Study

Quantitative Analysis of Selected Bone Parameters: Supplemental Report 3A: Trabecular Spacing and Orientation in the Long Bones

Science Discipline

Musculoskeletal

Investigator	Institute
M.M. Judy	Baylor University Medical Center

Co-Investigator(s)	Institute
none	

Research Subject(s)

Rattus norvegicus (Wistar Rat)

7 Flight Male

Ground-Based Controls

7 Vivarium

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 428; Hardware p. 456

Objectives/Hypothesis

Past data suggest mineral loss is prevalent in weight-bearing bones following space flight. The primary goal of this research was to quantitatively determine, by optical diffraction techniques, changes in trabecular spacing (area density) and orientation under effects of weightlessness. One major goal of the research was to study changes throughout the area and height of both primary and secondary spongiosa in a trabecular region which is primarily weight bearing.

Approach or Method

Optical diffraction measurements were employed to determine the magnitude of changes in mean trabecular spacing and in mean trabecular orientation. The trabecular region immediately below the inferior-directed convexity of the cartilage growth plate, which is functionally related predominantly to sustaining mechanical forces of weight bearing and locomotion, was studied.

Results

Values of the ratio of mean trabecular spatial density, in a region 300 µm distal to the downward convexity in the cartilage growth plate, to the value adjacent to the plate, were significantly smaller ($p \leq 0.2$) for the flight animals than values for vivarium control animals. No significant differences were found in proximal regions, or detected in mean trabecular orientation. The increase in the ratio of trabecular spacing at 300 µm distal to that at the cartilage plate in the flight animals means that the linear trabecular density at this distance decreased under the reduced loading of weightlessness. Decreased values of trabecular spatial density, and of both osteoblastic activity and trabecular cross-sectional area noted in collateral research, suggest decreased modeling activity under weightlessness.

Title of Study

Quantitative Analysis of Selected Bone Parameters: Supplemental Report 3B: Mineralization in the Long Bones

Science Discipline

Musculoskeletal

Investigator

J.L. Matthews

Institute

Baylor University Medical Center

Co-Investigator(s)

none

Institute

Objectives/Hypothesis

The major objectives of this experiment were: 1) a microscopic study of growth plates and metaphyseal trabeculae to assess the type and functional state of bone cells and to characterize the zone of calcification of the cartilaginous growth and 2) an optical birefringent study of the trabeculae in order to assess trabecular number, size, shape, and orientation, as it is presumed that this metabolically active bone will reflect subtle changes that may result from a zero-gravity condition.

Approach or Method

Thin slices (< 1 µm) of tibial metaphysis and epiphyseal growth plate were examined with a transmission electron microscope. A check list of cell organelles, inclusions, and ultrastructural features were used during examination of all tissue sections in an effort to give a complete descriptive profile of the bone cells and matrix of representative sections of all experimental bones.

Research Subject(s)

Rattus norvegicus (Wistar Rat)

7 Flight Male

Ground-Based Controls

7 Vivarium, 7 Synchronous

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 428; Hardware p. 456

Results

Differences noted in osteoblasts of flight animals include: a reduced nucleolus (78%); an increase in heterochromatin; dispersion of Golgi components; a reduction in number but increase in size of Golgi vesicles (a result of fusion?); reductions in rough surfaced endoplasmic reticulum, the number and size of rough endoplasmic reticulum cysternae, and evidence of pinocytotic activity; as well as an overall flattening of the cell to characterize a decrease in cell metabolic activity, particularly its protein synthesizing and secreting activity. Reduction of new mineral nodules and irregularity of mineral surface contour suggest that the newly secreted osteoid was immature. Large number of nuclei per cell, reduction in brush border and cytoplasmic vacuoles in the flight group are indicative of a reduction of activity for each osteoclast. Some resorption activity was noted, however, and shallow matrix cavities in flight bone were observed. Whether each clast ultimately resorbs the same bone volume, simply requiring more time, will have to be established by double tetracycline studies.

Title of Study
Vertebral Body Strength of Rat Spinal Columns

Science Discipline
Musculoskeletal

Investigator	Institute
L.E. Kazarian	Air Force Aerospace Medical Research Laboratory

Co-Investigator(s)	Institute
none	

Research Subject(s)
Rattus norvegicus (Wistar Rat)

25 Flight Male

Ground-Based Controls
25 Vivarium, 25 Synchronous

Key Flight Hardware
Cosmos 1129 Russian Hardware Suite

More Information
Mission p. 139-44; Publications p. 428; Hardware p. 456

Objectives/Hypothesis
This investigation undertook a comparative analysis of biomechanical property data of rat vertebral bodies following space flight exposure. This study was to shed light on the effects of environment, relative vertebral body position, and loading rate on groups of rats sacrificed immediately at spacecraft recovery (R-0), and six (R+6) and twenty-nine days (R+29) postflight.

Approach or Method
Vertebral centra properties were determined by subjecting the specimens to simple compression loading; a screw gear test machine applies a load in compression by the motion of a movable crosshead. The values of stiffness, ultimate load, displacement to ultimate load, and energy to ultimate load were analyzed by analysis of variance (ANOVA) and Duncan's Multiple Range test.

Results
At R+0 in the flight animals, all of the properties showed that the vertebral body exhibits an increasing susceptibility to fracture. This reduction of bone strength was not homogeneous and dependent on vertebral level. The R+6 recovery data were inconclusive since they varied above and below the R+0 data. At R+29, ultimate load values showed a statistically significant increase in bone strength approaching that of the vivarium group. The results relating to the synchronous group were not consistent, in that at the end of the 29-day recovery period, the ultimate load data, in some cases, was greater than the ultimate load data of the vivarium.

Title of Study
Automatic Analysis of Muscle Fibers from Rats Subjected to Spaceflight

Science Discipline
Musculoskeletal

Investigator	Institute
K.R. Castleman	Jet Propulsion Laboratory

Co-Investigator(s)	Institute
Chui, L.A.	University of Southern California
Van Der Meulen, J.P.	University of Southern California

Research Subject(s)
Rattus norvegicus (Wistar Rat)

25 Flight Male

Ground-Based Controls
25 Vivarium, 25 Synchronous

Key Flight Hardware
Cosmos 1129 Russian Hardware Suite

More Information
Mission p. 139-44; Publications p. 429; Hardware p. 456

Objectives/Hypothesis
Space flight and microgravity are known to produce systemic and metabolic changes in animals and humans. Even though the effects of weightlessness in various organ systems are well described, the pathophysiological mechanism is largely unknown. In this experiment, muscle size and fiber type distribution were studied in the extensor digitorum longus (EDL) muscles.

Approach or Method
Muscle histochemistry of flight and control animals were analyzed in the Medical Image Analysis Facility at the Jet Propulsion Laboratory, which includes a microscope-mounted television camera capable of converting the specimen image into numerical form for computer processing. The computer program isolates the individual fibers, and measures the area, perimeter, and average optical density of each. A scatter plot is then produced showing how the fibers are distributed in diameter and optical density. Individual and mean fiber area were also printed with the program.

Results
Both fast-twitch and slow-twitch fibers showed a significant reduction in fiber area. With only two exceptions, the proportion of slow fibers was reduced by space flight. The ratio of slow fiber area to fast fiber area was lower in the flight groups, indicating that slow fibers suffer size loss more than do fast fibers. These results appear to give a snapshot of how muscle physiology adapts to the space flight environment. Hypogravity produces an insufficient loading mechanism, leading to hypokinesia and hypodynamia. This, in turn, produces trophic changes, particularly in antigravity muscles (or slow twitch oxidative fibers), decreased protein metabolism, negative nitrogen balance, etc., producing muscle atrophy as the final result. Slow fibers, important in maintaining posture against gravity, are of little use in space, and their size, and even proportion, were reduced by the adaptation process. Fast fibers also suffered a disuse atrophy, but to a lesser extent since they are used for locomotion.

Title of Study

The Effect of Spaceflight on Osteogenesis and Dentinogenesis in the Mandibles of Rats

Science Discipline

Musculoskeletal

Investigator	Institute
D.J. Simmons	Washington University School of Medicine, St. Louis

Co-Investigator(s)	Institute
Russell, J.E.	Washington University, St. Louis
Winter, F.	Washington University, St. Louis
Rosenberg, G.D.	Indiana/Purdue University
Walker, W.V.	Washington University, St. Louis

Research Subject(s)

Rattus norvegicus (Wistar Rat)

18 Flight Male

Ground-Based Controls

7 Vivarium, 12 Synchronous

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 429; Hardware p. 456

Objectives/Hypothesis

Efforts to understand how prolonged space flight effects changes in calcium homeostasis and bone formation-resorption have been pursued on past Cosmos missions. This study examines the effect of space flight on the integrated growth and remodeling of a non-weight bearing bone, the mandible and teeth, to determine how microgravity affects tissues in a skeletal element which is only supplied with a large antigravity muscle (masseter).

Approach or Method

Animals were injected with 1.0 mg/kg body weight of Declomycin to mark forming and mineralizing surfaces of bone and dentin, three days prior to loading. The left jaw was divided into three regions: premolar, molar, and postmolar. All sections were examined by UV microscopy to reveal the distribution of tetracycline time markers. Dentinogenesis was estimated in the portion of the mandibular incisor that lay within the diastema. Polished slabs of the lower incisors were scanned to measure local variations in calcium, phosphorus, and sulfur.

Results

The total calcium, inorganic phosphorus, and hydroxyproline levels in the jaws and incisors of the flight rats were normal. Gravity-density fractionation studies suggested, however, that space flight caused a delay in the normal maturation of bone and mineral matrix; these values were normalized at R+6 and were fully corrected by R+29. The teeth were spared. The circadian and ultradian patterns of calcified dentin were normal during space flight and recovery periods, but the enamel rhythms displayed a greater amplitude of sulfur concentrations and thus abnormal calcium/sulfur ratios during exposure to microgravity. The only derangements detected were in the quality of the matrix and mineral moieties. The highest density fractions of the flight rat bones had 30% less mineral and collagen than the corresponding fractions from the control rat bone. These changes suggest that there was a delay in the maturation of collagen (a lack of intramolecular cross-links?) and apatite mineral in the flight animals.

Title of Study

The Effect of Spaceflight on Osteogenesis and Dentinogenesis in the Mandible of Rats: Supplement 1: The Effects of Spaceflight on Alveolar Bone Remodeling in the Rat Mandible

Science Discipline

Musculoskeletal

Investigator	Institute
P. Tran Van	Yale University School of Medicine

Co-Investigator(s)	Institute
Vignery, A.	Yale University School of Medicine
Baron, R.	Yale University School of Medicine

Research Subject(s)

Rattus norvegicus (Wistar Rat)

18 Flight Male

Ground-Based Controls

18 Vivarium, 18 Synchronous

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 429; Hardware p. 456

Objectives/Hypothesis

Under space flight conditions, and assuming animals are eating normally, alveolar bone should be subjected to only slightly different mechanical conditions, which should not induce marked changes in bone remodeling if all other metabolic conditions are unchanged. On the other hand, if the changes observed in the long bone are due totally or in part to systemic changes, alveolar bone remodeling should also be affected, and even more markedly considering its high normal turnover rate.

Approach or Method

The molar area was dissected from the right lower jaw and embedded without decalcification. Horizontal sections (4 µm) from the cervix to the apex of the root were prepared with a microtome. Sections from middle part of the buccal root of the first molar were stained for examination, one section out of every five of these was prepared for fluorescent microscopic analysis. A technique of dynamic histomorphometry was used to determine the extent and duration of each phase in the bone remodeling sequence, the mean calcification rate, and the amount of bone mineralized per day.

Results

The results obtained showed the absence of effects of space flight upon the balance between bone formation and resorption. There was, however, a slight but constant decrease in the alveolar bone turnover rate. This decreased remodeling activity, although present in the synchronous animals, was significantly lower in the flight animals, even after a three-week recovery period. In terms of bone remodeling activity, results indicated a decrease in the birth rate of new Basic Multicellular Units (BMU) at the tissue level rather than an abnormal activity at the BMU or the cellular levels. The most dramatic effect of space flight was observed along the periosteal surface, and especially in areas not contiguous with (covered with) masticatory muscles, where bone formation almost stopped completely during the flight period. As this bone was submitted to the same mechanical forces in the flight animals and controls, it was concluded that factors other than mechanical loading might be involved in the decreased bone formation during space flight.

Title of Study

Bone Resorption in Rats During Spaceflight

Science Discipline

Musculoskeletal

Investigator	Institute
C.E. Cann	University of California, San Francisco

Co-Investigator(s)	Institute
Adachi, R.R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 430; Hardware p. 456

Objectives/Hypothesis

Calcium metabolism is altered in weightlessness. In humans, bone loss occurs and urinary calcium output is increased. Experiments on previous Cosmos flights have shown that bone formation in the tibia is depressed in young, growing rats, but no direct information has been obtained about bone resorption, or any of the other calcium metabolic parameters such as excretion, absorption, or net calcium balance. The basis of the present study was to determine the response of calcium homeostasis and bone to weightlessness.

Approach or Method

Calcium tracer kinetic methods were used in this study. In the normal situation, both bone and dietary calcium are made up of natural calcium, and thus are labeled with stable isotopic tracers such as ^{48}Ca. If one removes ^{48}Ca from the diet, however, then dietary calcium is distinguished from bone calcium by lack of this tracer. This is done by replacing natural dietary calcium with isotopically-separated ~100% ^{40}Ca. As calcium is excreted from the serum, it is replaced by calcium coming from both bone and diet. As the only source of ^{48}Ca is the bone, the amount found in serum represents the fraction of calcium turnover coming directly from bone. Animals were started on the tracer diet at the time of loading into flight hardware. Specimens received from the Soviets following flight were the rib cage (left and right) from each animal and approximately 50% of each two-day excreta collection from each animal. The muscle from each rib cage was used as an indicator of tracer activity in the serum.

Results

Bone resorption expressed as the fraction of exchangeable calcium pool coming from bone was 0.690 ± 0.089 in the flight animals versus 0.675 ± 0.085 in synchronous controls, measured at the end of the flight period. Bone resorption rate at the end of the flight period was 15.7 mg Ca/day in flight rats and 20.2 mg Ca/day in the controls. It is significant that resorption normalized by calcium turnover does not decrease during flight, so that the decrease seen in the bone resorption rate is probably secondary to a decrease in total calcium turnover. Of particular interest may be the fact that while bone resorption rate decreased during flight, it was still 75-80% of normal at the end of the flight. This may indicate that bone loss on even longer flights will continue. The continual imbalance of bone formation and breakdown, and the large excretion of other minerals (sodium, potassium) from the body indicate that mineral homeostasis does not adapt to weightlessness.

Title of Study

Long-Term Effects of Weightlessness on a Biological System

Science Discipline

Plant Biology

Investigator	Institute
R. Baker	Colorado State University

Co-Investigator(s)	Institute
Hendrix, J.	Colorado State University
Curtis, C.R.	University of Delaware

Research Subject(s)

Daucus carota (Carrot) inoculated w/*Agrobacterium tumefaciens*

2 Flight Containers (16 disks/canister)

Ground-Based Controls

Synchronous; Vertical Rotated; Horizontal Rotated; Vertical Clinostat; Horizontal Clinostat (gravity-compensated)

Key Flight Hardware

Carrot Tissue Containers: Tumor Growth Container II; Temperature Recording System

More Information

Mission p. 139-44; Publications p. 430; Hardware p. 476-7, 552-3

Objectives/Hypothesis

Plants orient to the direction of the gravitational field and contain supporting structures made necessary by the presence of gravity. Even so, only two gross responses of plants to gravity are known. The first is geotropism; the second is related to the increased metabolic activity associated with gravity compensation. This experiment undertook the development of a biological system with the capacity to investigate the long-term effects of weightlessness on plant metabolism, cellular and tissue morphology, and physiology.

Approach or Method

A system involving the generation of crown gall tumors induced by *Agrobacterium tumefaciensConn*. on root disks of carrot was developed. Inoculated disks were incubated at 25°C for 72 hours to allow initiation of tumors, and chilled to 4°C to arrest growth until launch. Measurable parameters of responses to gravity compensation were established in ground based experiments (gravity compensated) and both flight and ground specimens were studied by carbohydrate analysis. Sugars were extracted from freeze-dried disks, and the dilution factor and disk weight were accounted for when calculating the final concentration of reducing sugars present in the carrot disk. For non-reducing sugars, values obtained from reducing sugars was subtracted from values calculated from a second aliquot. Starch was determined from shredded disk samples.

Results

Weights of tumors produced on the spacecraft were not significantly different from those developed at 1 g. Tumors produced in gravity-compensated conditions (clinostat rotation), however, were significantly larger, which confirms previous experimentation. This suggests that clinostat rotation does not simulate weightlessness. While orientation of cellular organelles in weightlessness may be comparable to that in gravity, the results indicate no increase in metabolic activity (as reflected in tumor size). However, carbohydrate levels were found to be similar in flight and gravity-compensated material, a surprising result, for soluble carbohydrates must have been supplied to tumors for growth. Also, the change of ratios for gravity-compensated and flight material were both positive, indicating that soluble components were depleted relatively more than starch, while results for stationary ground controls were negative, indicating that starch was more depleted than soluble sugars.

Title of Study

Long Term Effects of Weightlessness on a Biological System-Isoenzyme Analysis: Supplemental Report Number 1

Science Discipline

Plant Biology

Investigator	Institute
C.R. Curtis	University of Delaware

Co-Investigator(s)	Institute
Podleckis, E.V.	University of Delaware
Golt, C.M.	University of Delaware

Research Subject(s)

Daucus carota (Carrot) inoculated w/*Agrobacterium tumefaciens*

2 Flight Containers (16 disks/canister)

Ground-Based Controls

Synchronous; Vertical Rotated; Horizontal Rotated; Vertical Clinostat; Horizontal Clinostat (gravity-compensated)

Key Flight Hardware

Carrot Tissue Containers: Tumor Growth Container II; Temperature Recording System

More Information

Mission p. 139-44; Publications p. 430; Hardware p. 476-7, 552-3

Objectives/Hypothesis

The main objective of the gel electrophoresis study was to determine if weightlessness or other gravity treatments altered the isoenzyme profile of crown gall tumors. This objective was extended to include nontumored cortex and stele tissue. Although tumor growth in weightlessness was minimal, and the amount of material available for study was limited, it was decided to proceed with electrophoretic analysis where a sufficient amount of tumor tissue was available.

Approach or Method

A system involving the generation of crown gall tumors induced by *Agrobacterium tumefaciensConn.* on root disks of carrot was developed, which was responsive to gravity treatments. Lyophilized carrot disk samples and frozen tumor samples were weighed and ground; the homogenate was centrifuged; and the supernatant served as the sample for electrophoresis. Protein concentrations were estimated by spectrophotometric protein assay. Isoenzyme patterns were examined after isoelectric focusing of samples in polyacrylamide gel cylinders. Gels were then stained for general proteins, esterase, acid phosphatase, and peroxidase.

Results

Several repeated electrophoretic trials failed to yield consistent results with general protein stains. Similarly, peroxidase isoenzyme patterns were difficult to assay because of a high degree of background interference in the gels. Six major bands of esterase activity were found in all tissues. When the approximate pH values were determined from 1 mm sliced gels, a linear regression was apparent as the pH value for each band changed slightly, with values ranging from 5.36 to 4.38. Although the disk tissue was separated into cortex and stele, the esterase pattern was unchanged. The gravity treatments did not appear to affect the esterase enzyme pattern. No other conclusions could be made from the protein, peroxidase and acid phosphate data because of a lack of sufficient material for complete analysis, non-uniform condition of the material, and inconsistent results.

Title of Study

Growth and Development of Carrot Cells and Embryos in Space

Science Discipline

Plant Biology

Investigator	Institute
A.D. Krikorian	State University of New York at Stony Brook

Co-Investigator(s)	Institute
Dutcher, F.R.	State University of New York
Quinn, C.A.	State University of New York
Steward, F.C.	State University of New York

Research Subject(s)

Daucus carota (Carrot)

2 Flight Containers (~900 embryos/ container)

Ground-Based Controls

2 Synchronous Containers (transportation control); 4 Stationary Units

Key Flight Hardware

Carrot Tissue Containers: Embryoid Container; Temperature Recording System

More Information

Mission p. 139-44; Publications p. 430; Hardware p. 476-7, 552-3

Objectives/Hypothesis

A major area of research in space biology has been to ascertain whether plant development can proceed normally and consecutively in the weightless state, especially the salient feature in which a cell gives rise to a multicellular unit and thence to an embryo with shoot and root growing regions. In this study, morphogenetically competent pro-embryonic cells and well developed somatic embryos of carrot at two levels of organization were exposed for 19.5 days to a hypogravity environment.

Approach or Method

Carrot cells in petri dishes in special canisters exposed to weightlessness were compared to those maintained on Earth. Cultures were chilled to 4°C to arrest growth until lift-off, and temperatures were recorded to provide the inflight temperature profile. Postflight, materials were maintained at 4°C until arrival in the U.S., where they were examined, photographed, and fixed with glutaraldehyde. Methods of counting and scoring embryonic units, and rearing plantlets to maturity were followed.

Results

There was no detectable difference between the subsequent ability of any of the stages of embryos or plantlets which had developed in space to continue their course of growth and development. It was confirmed that cultured totipotent cells of carrot can give rise to embryos with well-developed roots and minimally developed shoots. It was also shown that the space hypogravity environment could support the further growth of already organized later somatic embryonic stages and give rise to fully developed embryo-plantlets with roots and shoots. It should be emphasized, though, that carrot materials flown necessarily had prior exposure to 1 g conditions. Tests must be made to dispose of any possibility that the free cells that organize in space into embryos (and embryos into plantlets) need to have had a recent "experience" and consequent "memory" of growth and development under 1 g for their later successful development in microgravity.

Title of Study

Space Radiation Dosimetry Aboard Cosmos 1129: U.S. Portion of the Experiment

Science Discipline

Radiation/Environmental Health

Investigator	Institute
E.V. Benton	University of San Francisco

Co-Investigator(s)	Institute
Henke, R.P.	University of San Francisco
Frank, A.L.	University of San Francisco
Johnson, C.S.	University of San Francisco
Etter, E.	University of San Francisco
Tran, M.T.	University of San Francisco
Cassou, R.M.	University of San Francisco

Research Subject(s)

Not Applicable

Ground-Based Controls

Not Applicable

Key Flight Hardware

Radiation Detectors: Cosmos 1129 Radiation Detector Packets, Cosmos 1129 Corner Stacks

More Information

Mission p. 139-44; Publications p. 430-31; Hardware p. 528-31

Objectives/Hypothesis

The purpose of this experiment was to provide a comprehensive picture of the radiation exposure experienced by the Cosmos 1129 spacecraft and its contents. The measurements included and distinguished between the low- and high-LET radiation components, and also provided an approximate determination of the neutron exposure.

Approach or Method

Detectors were placed inside and outside the spacecraft hull. Included were stacks of plastic nuclear track detectors (PNTDs) for measurements of high-LET particles (Z 6), fission-foil detectors for neutron measurements, and thermoluminescent detectors (TLDs) for measurement of total doses due to charged particles and gamma rays.

Results

The high-LET particles registered, given as Z spectra and LET spectra, were translated into rem dose as a function of LET. The total accumulated doses for the particles (LET > 100 keV/µm) were 9.9 mrem inside and 25 mrem outside the spacecraft. The thermal, resonance, and high-energy neutron doses were found to be 0.52, 7.4, and 125 mrem, respectively, and the interior TLD dose was 347 mrad. The estimated error for this value is ± 50% and results from an uncertainty in the correct background subtraction for the dosimeters due to an unexplained spurious irradiation of all the detectors.

Title of Study

Studies of Specific Hepatic Enzymes and Liver Constituents Involved in the Conversion of Carbohydrates to Lipids in Rats Exposed to Prolonged Spaceflight

Science Discipline

Regulatory Physiology

Investigator	Institute
S. Abraham	Bruce Lyon Memorial Research Laboratory

Co-Investigator(s)	Institute
Klein, H.P.	NASA-Ames Research Center
Lin, C.Y.	Bruce Lyon Memorial Research Lab.
Tigranyan, R.A.	Institute of Biomedical Problems
Volkmann, C.	NASA-Ames Research Center
Vetrova, E.G.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

25 Flight Male

Ground-Based Controls

25 Vivarium, 25 Synchronous

Key Flight Hardware

Cosmos 1129 Russian Hardware Suite

More Information

Mission p. 139-44; Publications p. 431; Hardware p. 456

Objectives/Hypothesis

Examination of liver, blood, muscle, and skeletal tissues from rats aboard earlier Cosmos flights indicated changes in the lipid and carbohydrate levels of these tissues in response to space flight. These metabolic alterations, both in enzyme levels and in hepatic constituents, appeared to be unique to the weightless condition. The present study was designed to reinvestigate some of these earlier observations and to extend the range of inquiry to include additional hepatic microsomal and mitochondrial enzymes, as well as other liver constituents (total lipids, triglycerides, phospholipids, and sterols) not included in the original Cosmos 936 protocol.

Approach or Method

The activities of 26 enzymes concerned with carbohydrate and lipid metabolism in hepatic tissue were investigated. These activities were measured in the various hepatic cell compartments (i.e. cytosol, mitochondria, and microsomes). In addition, the levels of glycogen, total lipids, phospholipids, triglycerides, cholesterol, cholesterol esters, and the fatty acid composition of the rat livers were examined and quantified.

Results

The activities of most of the hepatic enzymes and liver constituents were unaffected by space flight. In confirmation with Cosmos 936 results, a significant difference was again found in the ability of flight animals to complex long-chain fatty acids. Thus, both microsomal diglyceride acyltransferase and microsomal cholinephosphotransferase of the flight rats showed reduced activities when compared with the synchronous controls; however, these decreased enzyme activities did not appear to affect the hepatic lipid values. The livers of the flight rats had 30% more glycogen than those of synchronous controls, yet flight animals showed no significant changes in the activities of glycogen synthesis or of phosphorylase that could fully explain the increased glycogen contents. It would appear that weightlessness can indeed affect metabolic pathways concerned with lipid and carbohydrate metabolism, and that such metabolic changes are in some cases independent of stresses, other than weightlessness, which are involved in space flight.

Title of Study
Studies of the Nasal Mucosa

Science Discipline
Regulatory Physiology

Investigator
L.M. Kraft

Institute
NASA-Ames Research Center

Co-Investigator(s)
none

Institute

Research Subject(s)
Rattus norvegicus (Wistar Rat)

18 Flight Male/Female

Ground-Based Controls
18 Vivarium, 18 Synchronous

Key Flight Hardware
Cosmos 1129 Russian Hardware Suite

More Information
Mission p. 139-44; Publications p. 431; Hardware p. 456

Objectives/Hypothesis
The basis for the present study was to determine if the lesions that were seen in the olfactory, but not respiratory, nasal mucosa of rodents in the experiment flown onboard Apollo-17 would be repeated. A further rationale involved the fact that the olfactory sense in rodents influences mating behavior. Thus, should these lesions develop during flight, with presumably impaired olfactory sense, they might be a contributing cause of the failure to mate seen in the rat ontogenesis experiment, should that indeed have been the case.

Approach or Method
After decalcification, each specimen (consisting of the remainder of the head after removal of brain, pituitary, eyes and mandible) was divided coronally into three segments, so that respiratory mucosa, predominating in the anterior, and olfactory mucosa, more abundant in the posterior portion, could be studied without having to make numerous serial or step sections. In evaluating the tissues microscopically, slides were read without knowing the identity of the tissues until all had been examined. Any lesions found were scored on the basis of their severity and extent.

Results
Lesions similar to those in the Apollo-17 flight animals were not found, leaving their etiology still in doubt. The posterior regions of the olfactory nasal mucosa of flight rats failed to reveal any histopathological changes. However, in the anterior aspect of the nasal cavity of the flight rats, focal lesions of moderate severity and variable extent were seen. These were consistent in character with that of a mild virus infection, which, it is postulated, was self-limiting. The infection was present in all groups of animals: flight, synchronous, and vivarium control. This is not to say that the animals are not to be considered specific pathogen free (SPF), for it is only reasonable to expect SPF animals to become infected from random sources after they leave the SPF environment. In any case, the results seem to illustrate the effect that stress, as exemplified by actual or simulated space flight, may have on an enzootic infection, even though it may have been subclinical in character.

Title of Study
Effects of Weightlessness on Body Composition in the Rat

Science Discipline
Regulatory Physiology

Investigator	Institute
G.C. Pitts	University of Virginia

Co-Investigator(s)	Institute
Ushakov, A.S.	Institute of Biomedical Problems
Pace, N.	University of California, Berkeley
Smith, A.H.	University of California, Davis
Smirnova, T.A.	Institute of Biomedical Problems

Research Subject(s)
Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls
5 Synchronous

Key Flight Hardware
Cosmos 1129 Russian Hardware Suite

More Information
Mission p. 139-44; Publications p. 431; Hardware p. 456

Objectives/Hypothesis
While organisms have evolved defenses against changes in temperature, altitude, osmotic pressure, etc., they have had no need or opportunity to evolve defenses against changes in the chronic acceleration field (DG, gravity). Thus, it comes as no surprise that DG perturbs body composition to a degree not seen with changes in most other environmental factors. As weightlessness represents a virtual extinction of the acceleration field, it is of basic physiological interest and has obvious applicability to space medicine. This study sought to characterize the body composition responses of the adult rat to weightlessness of 18.5 days duration.

Approach or Method
Dissection involved separation and weighing of fifteen individual organs and systems. Aliquots were analyzed for nitrogen, potassium, phosphorus, magnesium, and sodium. Determination of water content (freeze-drying) and fat content (Soxhlet extraction) were carried out separately on three major body compartments: skinned, eviscerated carcass (musculoskeletal system); skin; and all other components pooled designated "viscera"). The following calculations were also employed: Net body mass = total body mass - fur, gut content, and urine; Intracellular water content = 0.73 x body cell mass; Extracellular water content = total body water - intracellular water; Body protein = 6.25 x body nitrogen; Body cell mass = 8.9 x body potassium; and Bone mineral = 2.93 x body calcium. Statistical significance between groups was evaluated with the t test.

Results
In comparison to synchronous controls, the flight group showed: a 6.7% reduction in total body water probably attributed to a 36.2% reduction in the extracellular compartment; reductions of 6.6% in musculoskeletal water and 17.2% in skin water; an apparent shift of some water from skin to viscera; and a 20% reduction in bone mineral mass. Among organ fresh masses, there was a 7.5% increase in kidneys and a 14.0% decrease in spleen. The results support the validity of the rat as an experimental model for gravitational studies and the usefulness of the body composition approach to gravitational physiology. It appears highly probable that by the end of the 18.5-day exposure there was a steady state in body composition, potentially regulated and characteristic of the new g level. While the reported changes might have been greater if recorded just before re-entry (instead of 32-36 hours postflight), it is believed that they reflect true effects of weightlessness. It appears reasonable, though, that the flight animals might have regained 15-20% of their live mass in the 1.5 days being considered here.

Title of Study

Cardiovascular Results from a Rhesus Monkey Flown Aboard the Cosmos 1514 Spaceflight, and Ground-Based Controls

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
H. Sandler	NASA-Ames Research Center

Co-Investigator(s)	Institute
Krotov, V.P.	Institute of Biomedical Problems
Stone, H.L.	NASA-Ames Research Center
Benjamin, B.	NASA-Ames Research Center
Hines, J.W.	NASA-Ames Research Center
Halpryn, B.M.	NASA-Ames Research Center
Kulaev, B.	Institute of Biomedical Problems
Krilov, V.	Institute of Biomedical Problems
Magedov, V.	Institute of Biomedical Problems
Nazin, A.N.	Institute of Biomedical Problems
	Institute of Biomedical Problems

Research Subject(s)

Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls

2 Synchronous

Key Flight Hardware

Cardiovascular Experiment Hardware; Combined Pressure/Flow (CPF) Cuff; Cosmos 1514 Russian Hardware Suite

More Information

Mission p. 145-52; Publications p. 431-32; Hardware p. 456-7, 470-73

Objectives/Hypothesis

This flight experiment was designed to determine whether blood pressure and flow relationships to the head change with weightlessness. The objectives of this experiment were: 1) to develop a conscious rhesus monkey model to record carotid pressure and flow in a nonstressed animal; 2) to determine the effects of weightlessness on pressure-flow relationships to the head; and 3) to correlate cardiovascular findings with other simultaneously recorded physiologic information before, during, and after the flight.

Approach or Method

A single cylindrical probe (CPF Cuff) containing both flow and pressure transducers was chronically implanted around the left common carotid artery. Flow was measured using Doppler ultrasonic crystals and the continuous wave technique. Data collection before, during, and after flight consisted of five minutes of continuous recording every two hours. For pressure, each beat was analyzed with respect to value at peak systolic (maximum) and diastolic (minimum) levels. Systolic and diastolic pressures were determined by averaging all the values detected in respective intervals. Mean blood pressure was derived as the average (integrated under the curve) for the entire twenty-beat or twenty-second interval. Carotid blood velocity was calculated as the mean, integrated area under the curve, for each beat, representing the sum of systolic and diastolic flow periods.

Results

The prevailing heart rates during flight (80 bpm to 130 bpm) provide evidence that the animal model developed for this flight represents a normal (nonstressed) state for the monkey. Relative levels of blood flow velocity and blood flow per minute decreased during days two to three of flight and included a decrease in signal amplitude fluctuations, suggesting that there was significant stress on the animal during this period. On the third day, there was a relative increase in amplitude of 24-hour fluctuations for all parameters, signifying the development of circulatory adaptive processes and associated neuroendocrine mechanisms. In summary, the monkey demonstrated from the first hour of flight, an increase in blood pressure, a decrease in blood flow velocity to the head, and an increase in common carotid artery peripheral vascular resistance. Following this, compensatory mechanisms were invoked leading to rapid adaptation of regional hemodynamics in response to general hemodynamic changes. Cardiovascular system changes were maximal on day two of flight, with signs of adaptation appearing on days three to five of flight.

Title of Study

Early Postnatal Development of Rats Exposed In Utero to Microgravity

Science Discipline

Cell/Developmental Biology

Investigator	Institute
J.R. Alberts	Indiana University

Co-Investigator(s)	Institute
Keefe, J.R.	Case Western Reserve University
Serova, L.V.	Institute of Biomedical Problems
Apanasenko, Z.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

4 Flight Mothers; 32 Flight Pups (8 per litter) Male/Female

Ground-Based Controls

5 Vivarium Mothers w/Pups; 5 Synchronous Mothers w/Pups

Key Flight Hardware

Cosmos 1514 Russian Hardware Suite

More Information

Mission p. 145-52; Publications p. 432; Hardware p. 456-7

Objectives/Hypothesis

The last trimester of the rat's gestational period is a stage of formation and differentiation of sensory and motor systems vital to early survival and postnatal maturation. As part of a broad research program designed to examine the adequacy of maternal care following space flight and evaluate the postnatal development of the infant rats, this study represents a preliminary appraisal of the functional status of sensory and motor systems in the infant rat. It charts some of the fundamental landmarks of maturation during the first two to three weeks of postnatal life.

Approach or Method

Five pregnant rats flown on the biosatellite (embryonic days thirteen to eighteen) were allowed to complete their pregnancies after recovery. These pups and their mothers were then examined in a comprehensive, quantitative study of sensory and behavioral development. A microcomputer system monitored the cages 24 hours/day and recorded (each fifteen minutes) the number and duration of maternal visits to the nest. Pups were inspected each day at the time of weighing to note their general appearance and check for landmark events. Sensory tests were performed to demonstrate the presence of functional responsiveness in selected modalities.

Results

Four of the flight females had normal deliveries of live offspring postflight. The postpartum cycle of lactation and maternal behavior was displayed by all dams. Olfactory, tactile, and vestibular perceptions were functional at birth. High frequency (40 KHz) auditory detection appeared impaired, and there were signs of possible vestibular supersensitivity. In contrast to data derived from flight animals sacrificed at recovery, the anatomical and functional picture presented by this study suggest that the five day interval between recovery and birth may have constituted an ontogenetically significant period of readaptation to gravity, during which time compensatory alterations in development removed or repaired perturbations exerted by the space environment.

Title of Study

Developmental Morphology of the Eye, Vestibular System, and Brain in 18-Day Fetal and Newborn Rats Exposed In Utero to Null Gravity During the Flight of Cosmos 1514

Science Discipline

Cell/Developmental Biology

Investigator	Institute
J.R. Keefe	Case Western Reserve University

Co-Investigator(s)	Institute
Alberts, J.R.	Indiana University
Krasnov, I.B.	Institute of Biomedical Problems
Serova, L.V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

10 Flight Female

Ground-Based Controls

10 Vivarium, 10 Synchronous

Key Flight Hardware

Cosmos 1514 Russian Hardware Suite

More Information

Mission p. 145-52; Publications p. 432; Hardware p. 456-7

Objectives/Hypothesis

If it is assumed that female mammals demonstrate adaptive physiological responses to null-gravity exposure similar to flown males, then questions of transplacental expression of a variety of systemic effects from null-gravity exposure become highly significant in evaluating the results of developmental studies under altered gravity. Such an initial study of both direct and potentially indirect transplacental impacts of null-gravity on neural structures during the relatively stable midlife period represents the main thrust of this experiment.

Approach or Method

Five pregnant rats (embryonic days thirteen to eighteen) flown on the biosatellite were sacrificed at the recovery site, and the fetal heads were preserved for morphological studies. Five remaining females were allowed to proceed with normal term delivery, with selected newborns sacrificed at litter culling and postnatal days fifteen and thirty. All heads were opened along the dorsal midline of the skull, prior to immersion fixation in modified Karnovsky biostabilizer. Analysis focused on the cerebral hemispheres, the peripheral vestibular apparatus and vision organs.

Results

Examinations of fetal specimens revealed an effect of space flight exerted upon the normal developmental progression of neuronal maturation, reflected in the following aspects of development: 1) the comparative overall systemic immaturity of the flight specimens most evident in ocular, vestibular, and cortical structures; 2) the presence of abnormal mitotic figure in or near neuronal regions displaying high levels of neuroblast generation and migration along sustentacular elements, such as the neuronal retina and cerebral plates; and 3) the apparent volume disturbances reflected in ocular, vestibular, cochlear and ventricular cavities, as well as disturbances in the development of their neuronal and non-neuronal complements. No such differences could be detected in newborn, or fifteen- and thirty-day-old pups. It is uncertain whether these effects are the result of direct exposure to the null-gravity environment or an expression of the space flight environment acting directly upon the dam, and indirectly, via the placenta, upon the developing fetus.

Title of Study
Synchronization of Primate Circadian Rhythms in Space

Science Discipline
Regulatory Physiology

Investigator	Institute
F.M. Sulzman	State University of New York

Co-Investigator(s)	Institute
Fuller, C.A.	University of California, Riverside
Moore-Ede, M.C.	Harvard Medical School
Klimovitsky, V.	Institute of Biomedical Problems
Magedov, V.	Institute of Biomedical Problems
Alpatov, A.M.	Institute of Biomedical Problems

Research Subject(s)
Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls
2 Synchronous

Key Flight Hardware
Circadian Rhythm Experiment Hardware; Cosmos 1514 Russian Hardware Suite

More Information
Mission p. 145-52; Publications p. 432; Hardware p. 456-7, 482-3

Objectives/Hypothesis
In natural conditions, mammalian circadian rhythms are normally externally and internally synchronized. Whereas many researchers feel that the circadian time-keeping system is endogenous, others argue that the timing system is exogenous, with an organism perceiving daily timing signals such as slight variations in gravity associated with the rotation of the earth. A test of this hypothesis would be to determine if circadian rhythms persist outside of the Earth's environment.

Approach or Method
Activity was monitored via a U.S.-developed sensor attached to the monkey's restraint jacket, and totaled over sixteen-minute intervals and fed into a data collection unit. Auxiliary temperature was monitored with a Soviet biotelemetry system; transmitter output was recorded at sixteen-minute intervals on another data collection unit. Ankle skin temperature was measured by thermistors also developed by the U.S. and recorded on the digital data collection unit. Data were analyzed by computer and plotted digitally. To evaluate the underlying repetitive circadian characteristics of the data, a waveform reduction was performed.

Results
The most significant differences from pre- and postflight values were detected in auxiliary and skin temperatures. However, it is clear that the circadian rhythms of activity and auxiliary temperature persist in space; there may be changes in mean level and amplitude, but as expected, rhythmicity is still quite evident. Ankle skin temperature displayed very little day/night variations. The auxiliary temperature of monkeys in space appears to be maintained at an average of 0.5° and 1.0°C lower level than on the ground. The ankle skin temperature is also low in space, and maintained just above ambient temperature. This probably reflects a decrease in cutaneous blood flow in space. The results of the period analyzed also suggest that entrainment to the light-dark cycle is not as strong in space as it is on Earth. It is possible that the non-24-hour cycle could reflect a changing waveform in space or an alteration in the phase relationship to the light cycle, or could indicate some sort of stress induced desynchronization.

Title of Study

Calcium Metabolism and Correlated Endocrine Measurements in Primates

Science Discipline

Regulatory Physiology

Investigator	Institute
C.E. Cann	University of California, San Francisco

Co-Investigator(s)	Institute
Patterson-Allen, P.	NASA-Ames Research Center
Adachi, R.R.	NASA-Ames Research Center
Ushakov, A.	Institute of Biomedical Problems
Kondratyev, Y.I.	Institute of Biomedical Problems
Rakhmanov, A.S.	Institute of Biomedical Problems
Oganov, V.S.	Institute of Biomedical Problems

Research Subject(s)

Macaca Mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls

2 Synchronous, 2 Laboratory

Key Flight Hardware

Cosmos 1514 Russian Hardware Suite

More Information

Mission p. 145-52; Publications p. 432; Hardware p. 456-7

Objectives/Hypothesis

The problem of calcium loss from the body during space flight had been long recognized; however, little is known about the initiating mechanism of this loss. Two hypotheses have been suggested in explanation: 1) a primary increase in bone resorption due to decreased mechanical stress on the bone or 2) a primary renal calcium leak. This experiment was to measure the initial responses of the calcium homeostatic system in nonhuman primates subjected to the space flight environment.

Approach or Method

The basis for this study was the "tracer" technique, in which direct measurements of changes in bone resorption are possible through isotopically labeled calcium. Fifteen days prior to launch, flight and control subjects were started on a diet laced with the isotopically labeled calcium. Excretion samples were collected pre- and postflight, and amounts of labeled calcium were detected by means of irradiation. Single lateral x-rays were obtained for the right and left arms and legs of one flight, two synchronous, and one laboratory monkey to provide high contrast and good radiographic detail for bone. No serum samples were received for the flight experiment, so the planned endocrine studies were not done.

Results

Results indicate that after five days of flight, the fraction of circulating calcium that comes from the bone was increased. A major point to be noted is that, even with a wide fluctuation in dietary calcium intake, urinary calcium output remained fairly constant over the two to three week period. Similar results have been noted in immobilized monkeys. However, the very low variation when expressed as calcium/creatinine suggests a technical explanation having to do with collection. Gross skeletal changes were not observed, but there was a suggestion of subtle changes as determined from the high-quality radiographs. Qualitative assessment of the films for cortical porosity suggests that one of the flight monkeys may have experienced a state of slightly increased bone turnover because of the presence of some intracortical striations in the radial and ulnar cortex. Data indicate that the methods used to study calcium metabolism during space flight were sufficient to answer the questions asked.

Title of Study

Effect of Microgravity on Blood Pressure and Flow in the Common Carotid Artery of Primates

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
H. Sandler	NASA-Ames Research Center

Co-Investigator(s)	Institute
Krotov, V.P.	Institute of Biomedical Problems
Osaki, R.	NASA-Ames Research Center
Hines, J.	NASA-Ames Research Center
Skidmore, M.	NASA-Ames Research Center
Agasid, E.	NASA-Ames Research Center
MacKenzie, R.	NASA-Ames Research Center
Bazunova, E.G.	Institute of Biomedical Problems
Belgorodsky, A.O.	Institute of Biomedical Problems
Estratov, Y.A.	Institute of Biomedical Problems
Nazin, A.N.	Institute of Biomedical Problems

Research Subject(s)

Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls

2 Synchronous, 2 Vivarium

Key Flight Hardware

Cardiovascular Experiment Hardware-Mod 1; Combined Pressure/Flow (CPF) Cuff; Cosmos 1667 Russian Hardware Suite

More Information

Mission p. 153-5; Publications p. 432-3; Hardware p. 457, 472-5

Objectives/Hypothesis

The experiment was designed to study cardiovascular changes in non-human primates exposed to the microgravity environment. As the results of Cosmos 1514 indicated that significant cardiovascular changes occur during space flight, the study conducted aboard Cosmos 1667 was to strengthen this conclusion. An additional feature of the experiment included a postflight control study using the flight animal.

Approach or Method

One flight subject, along with one half of the flight candidates, also received cardiovascular (CV) pressure and flow sensor implants (CPF Cuff), and respiration sensors. Since the CV flow and pressure transducers were subject to drift with variations in barometric pressure, a cross calibration method was developed. Both flight monkeys were also instrumented to record neurophysiological parameters. Intermittent postural tilt tests were conducted before and after space flight and synchronous studies to simulate the fluid shifts associated with space flight.

Results

The experiment results support the conclusion derived from Cosmos 1514 that significant cardiovascular changes occur with space flight. The changes most clearly seen were rapid initial decreases in heart rate and further decreases with continued exposure to microgravity. The triggering mechanism appeared to be a headward shift in blood and tissue volume which, in turn, triggered adaptive cardiovascular changes. Dramatic increases in arterial pulse pressure may indicate the inflight hemodynamic adjustments to this headward fluid shift. The adaptive responses could be a means to maintain adequate oxygen delivery to the brain under these circumstances. Adaptive changes took place rapidly and began to stabilize after the first two days of flight. However, these changes did not plateau in the animal by the last day of the mission, and heart rate and blood pressure did not demonstrate evidence of stabilization by the end of the flight.

Title of Study

Morphological and Biochemical Examination of Heart Tissue: I. Effects of Microgravity on the Myocardial Fine Structure of Rats Flown on Cosmos 1887 - Ultrastructure Studies

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
D.E. Philpott	NASA-Ames Research Center

Co-Investigator(s)	Institute
Kato, K.	NASA-Ames Research Center
Sapp, W.	Tuskegee University
Popova, I.A.	Institute of Biomedical Problems
Serova, L.V.	Institute of Biomedical Problems
Miquel, J.	Linus Pauling Institute of Medicine
Stevenson, J.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 433; Hardware p. 457

Objectives/Hypothesis

Vascular deconditioning, which is an important medical problem, is recognized as one of the key concerns of space flight research. This loss of physiological performance of the circulatory system is accompanied by disuse muscle atrophy triggered by the reduced functional load of the musculoskeletal system in the microgravity environment. Animal models are often used to examine disuse atrophy because they are more amenable to morphological and biomedical research needed to unravel the mechanisms of muscle breakdown. Using these models, one could design preventive countermeasures. The present study seeks to expand this previous research.

Approach or Method

Tissue was obtained for study of the effects of microgravity on the myocardium. The left ventricles of hearts from rats flown on the biosatellite were compared to the same tissue of synchronous and vivarium control animals using a minimum of 100 electron micrographs from each animal. Volume density of the mitochondria was determined by point counting, using 8x10 micrographs at a magnification of 27,500x.

Results

Structural changes seen in the flown rats include some loss of microtubules and fibrillar edema that may be linked to tissue breakdown, with a concomitant increase in osmotic pressure and fluid entry into the cells. Intermittent areas of missing protofibril (actin, myosin filaments) were observed in cross sections of flight tissue which is indicative of muscle breakdown. Point counting of the mitochondria in the left ventricle resulted in a mean of 39.9 for the vivarium, 38.9 synchronous, and 32.5 for the flight tissue. It is clear that the volume density of the mitochondria in the flight group was reduced by a significant amount. Capillary alterations were also seen in the flight tissue in the form of numerous endothelial invaginations projecting into the lumen of the capillaries. The present data support the view that an optimum work load imposed on the heart (i.e., moderate physical exercise at normal Earth gravity) is essential for preservation of mitochondrial structure and function.

Title of Study

Morphological and Biochemical Examination of Heart Tissue: II. Cellular Distribution of Cyclic AMP-Dependent Protein Kinase Regulatory Subunits in Heart Muscle of Rats Flown on Cosmos 1887

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
M. Mednieks	Northwestern University

Co-Investigator(s)	Institute
Popova, I.A.	Institute of Biomedical Problems
Serova, L.V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 433; Hardware p. 457

Objectives/Hypothesis

The study was undertaken in order to gain insight into the mechanistic aspects of cardiac changes that both animals and humans undergo as a consequence of space travel. A number of physiologic changes, attributed to space travel conditions in experimental animals and humans, can be the consequence of increased circulating levels of catecholamine hormones. In this study, the cellular compartmentalization and biochemical localization of regulatory subunits (R-subunits) of cyclic AMP-dependent protein kinase (cAPK) of ventricle heart tissue obtained from space-flown rats were determined.

Approach or Method

Photoaffinity labeling with a ^{32}P-8-azido analog of cyclic AMP, and electrophoretic separation of the proteins, was followed by autoradiographic identification of the subcellular fraction in which the labeled R subunits are localized. Similarly, antibodies to R-subunits were prepared and employed in an immunogold electron microscopic procedure to directly visualize cellular compartmentalization of the cAPK R-subunits.

Results

Results showed that protein banding patterns in both the cytoplasmic fraction and in a fraction enriched in chromatin-bound proteins showed some individual variability in tissues of different animals, but exhibited no changes that can be attributed to the flight. Examination of cellular localization of the isotopically labeled R-subunits of cAPK isotopes showed no change in the distribution of RI in either soluble or particulate fractions, whereas the presence of RII in the particulate subcellular fraction as well as in regions of nuclear chromatin was greatly decreased in tissues from rats in the flight group when compared to controls. These findings indicate that a major catecholamine hormone regulated mechanism in cardiac tissue is altered during some aspect of space travel.

Title of Study

Effect of Spaceflight on Levels and Function of Immune Cells

Science Discipline

Immunology/Microbiology

Investigator	Institute
A.D. Mandel	NASA-Ames Research Center

Co-Investigator(s)	Institute
Sonnenfeld, G.	University of Louisville
Taylor, G. R.	NASA-Johnson Space Center
Fuchs, B. B.	Institute of Human Morphology
Berry, W.	University of Louisville
Wellhausen, S.R.	University of Louisville
Konstantinova, I.	Institute of Biomedical Problems
Lesnyak, A. T.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 433; Hardware p. 457

Objectives/Hypothesis

The purpose of this experiment was to begin a systematic attempt to define the range of immunological parameters affected by space flight. Two different areas were chosen for study. First, the effect of space flight on the ability of cells to respond to an external immunological stimulus was determined. Second, the effects of space flight on the expression of cell surface markers of spleen and bone marrow cells was examined. These markers represent various immunologically important cell populations; an alteration in the percentage of cells expressing the markers could result in an alteration of the immunological function.

Approach or Method

In the first experiment, rat bone marrow cells were examined in Moscow for their response to colony stimulating factor-M. In the second experiment, rat spleen and bone marrow cells were stained with a variety of antibodies directed against cell surface antigenic markers. These cells were analyzed using an autofluorograph interfaced with a computer system.

Results

The results of the studies indicate that bone marrow cells from flight rats showed a lower response to colony stimulating factor than did bone marrow from control rats. There was a higher percentage of spleen cells from flight rats staining positively for pan-T-cell, suppressor-T-cell, and innate interleukin-2-receptor antigens than from control animals. In addition, a higher percentage of cells that appeared to be part of the myelogenous population of bone marrow cells from flight rats stained positively for surface immunoglobulin than did equivalent cells from control rats. This experiment presents additional data to indicate that space flight, even of a relatively short duration, affects certain parameters of the immune system. Through this study, it was possible to demonstrate some specific cell populations that appear to be affected by space flight.

Title of Study

Distribution and Biochemistry of Mineral and Matrix in the Femurs of Rats

Science Discipline

Musculoskeletal

Investigator	Institute
S.B. Arnaud	NASA-Ames Research Center

Co-Investigator(s)	Institute
Durnova, G.	Institute of Biomedical Problems
Mechanic, G.L.	University of North Carolina
Bromage, T.G.	The London Hospital Medical College
Buckendahl, P.	University of Santa Cruz
Boyde, A.	University College, London
Elliott, J.C.	London Hospital Medical College

Research Subject(s)

Rattus norvegicus (Wistar Rat)

6 Flight Male

Ground-Based Controls

6 Basal, 6 Vivarium, 6 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 433-4; Hardware p. 457

Objectives/Hypothesis

Previous analyses of the composition of mineral and matrix in the bone of young rats following space flight has revealed deficits in calcium, phosphorus, and osteocalcin, a noncollagenous protein, without an associated decrease in collagen. To characterize the location and nature of this mineralization defect in a weight bearing long bone, the femur, this study attempted to relate the spatial distribution of mineral *in situ* in the proximal, central, and distal thirds of the femoral diaphysis to the biochemical composition of the bone from the same areas.

Approach or Method

Localizing mineralization activity in the diaphysis of the femur to proximal, central, and distal thirds was determined by chemical analysis of pooled bone samples. Since statistical analyses of a determination from a single pool could not be done, a value two standard deviations above or below the error of the method was used to denote the difference in two comparison groups (i.e., exceeding 6% for calcium, 12% for phosphorus, and 10% for hydroxyproline and osteocalcin, etc.). A new technique, x-ray microtomography, with a resolution of 26 microns, was used to obtain semi-quantitative data on mineral distribution in reconstructed sections of wet whole bone.

Results

Biochemical analyses revealed lower concentrations of calcium, phosphorus, and osteocalcin, but not collagen, in the distal half of the diaphysis of flight animals compared to synchronous controls. Collagen concentration was reduced only in the proximal half of the diaphysis. X-ray microtomography indicated a longitudinal gradient of decreasing mineralization toward the distal diaphysis similar to the biochemical analysis. Image analysis of cross-sections by backscattered electrons in a scanning electron microscope revealed patterns of mineral distributions that varied with the site of the section in flight and synchronous controls. Circulating parameters of skeletal metabolism revealed differences in serum calcium, osteocalcin, and alkaline phosphatase in the flight groups suggestive of steroid hormone excess, a phenomenon supported by the finding of enlarged adrenal glands.

Title of Study

Biomedical, Biochemical, and Morphological Alterations of Muscle and Dense, Fibrous Connective Tissues During 14 Days of Spaceflight

Science Discipline

Musculoskeletal

Investigator	Institute
A.C. Vailas	University of California, Los Angeles

Co-Investigator(s)	Institute
Kaplansky, A.	Institute of Biomedical Problems
Zernicke, R.	University of California, Los Angeles
Grindeland, R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

4 Flight Male

Ground-Based Controls

5 Basal, 4 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 434; Hardware p. 457

Objectives/Hypothesis

In consideration of the differences between the rodent experiments on U.S.S.R. and U.S. space flights, this experiment was designed to generate comparative data about the sensitivity of cortical bone (humerus) and trabecular bone (vertebral, T7) to caging environment, diet, and rat strain differences. Specifically this study provided data regarding the biochemical, biomechanical, and morphological characteristics of selected connective tissues (humerus, vertebral body, tendon, and skeletal muscle) for growing rats, maintained under different feeding and caging conditions (including weightlessness).

Approach or Method

Studies of biochemical, biomechanical, and morphological characteristics of selected connective tissues (humerus, vertebral body, tendon, and skeletal muscle) were performed on flight and control animals. Additionally, for two weeks, male Taconic-Sprague Dawley and Czechoslovakian-Wistar rats were maintained in flight simulation cages (one rat/cage=U.S.; ten rats/cage=U.S.S.R.) and fed U.S.S.R. or U.S. diets to compare different combinations of dietary and caging procedures (U.S. diet in U.S.S.R. cage, U.S.S.R. diet in U.S. cage, etc.).

Results

Using the basal group for comparison, during the 12.5-day period, the humeral lengths increased 4.2% for vivarium controls, 1.4% for synchronous controls, and 0.04% for flight rats. The average flexural rigidity (bending stiffness) of flight humeri were significantly less than the vivarium (40%) and synchronous (35%) controls, but the average flexural rigidity of the flight humerus was not different from the basal control group. The flight group had an average ventral body (L6) compressional stiffness that was 39% less than vivarium, 46% less than synchronous, and 16% less than basal controls. There seemed to be no significant effect upon the collagen concentration in various types of skeletal muscles. On average all rats increased (>60%) their body mass, and there were no differences among humeral lengths for different groups. The vertebra (T7) displayed no significant structural differences, but material properties were influenced by all three factors; generally, the combination of factors that produced significantly greater material properties were U.S.S.R. caging and diet, and the Wistar rat strain.

Title of Study

Gravity and Skeletal Growth: I. Gravity and Skeletal Growth

Science Discipline

Musculoskeletal

Investigator	Institute
E.M. Holton	NASA-Ames Research Center

Co-Investigator(s)	Institute
Berretta, D.	University of Pennsylvania
Doty, S.	Colombia University
Roberts, W.E.	Indiana University School of Dentistry
Garetto, L.	Indiana University School of Dentistry

Research Subject(s)

Rattus norvegicus (Wistar Rat)

10 Flight Male

Ground-Based Controls

10 Basal, 10 Vivarium, 10 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 434; Hardware p. 457

Objectives/Hypothesis

Past data suggest that matrix turnover is altered during space flight which in turn decreases the amount of bone added; either this defect alters the size of bone crystals formed or the flight environment somehow impedes crystal growth independent of matrix production. This suppressed bone formation may be a major factor in the failure of bone to increase its strength. The objectives of the Cosmos 1887 study were to continue the investigation of space flight on bone in growing rats.

Approach or Method

Strength tests on humeri, analysis of bone composition, including maxillae w/ teeth, calvaria, tibial shaft, and thoracic vertebra (general overview) were performed. Studies also included measuring bone area, bone electrophysiology, bone vascularity, osteoblast morphology, and osteoblast histogenesis. Electrophoresis was used as a direct method for determining the zeta potential for particles. The bone particle velocity was measured in a fluid with a given ion concentration while an electric field of known amplitude was applied. The ratio a particle velocity to the electric field amplitude was defined as the electric mobility (EMP), which, in turn, was proportional to the zeta potential.

Results

The flight group lost an average of 13 g over a twenty-day period compared to the basal group (-0.65 g/day). Visual observations of tibial cross sections under bright-field or polarized light did not show any obvious differences. The synchronous and vivarium control groups have very similar EPMs while the basal group is slightly less electronegative and the flight group is more electronegative than the controls. The synchronous animals, which gained the most weight, had essentially normal zeta potential values, while the flight group had a more negative potential, indicating net bone formation, than all other groups. Interestingly, the potential in the flight rats is in the opposite direction of osteoporotic bone (that is, more negative rather than more positive EPM values). Whether the value reflects increased matrix synthesis during flight or postflight recovery is not known.

Title of Study

Gravity and Skeletal Growth: II. Morphology and Histochemistry of Bone Cells and Vasculature of the Tibia from Cosmos 1887

Science Discipline

Musculoskeletal

Investigator	Institute
S.B. Doty	Columbia University

Co-Investigator(s)	Institute
Durnova, G.	Institute of Biomedical Problems
Kaplansky, A.	Institute of Biomedical Problems
Morey-Holton, E.R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

10 Flight Male

Ground-Based Controls

10 Basal, 10 Vivarium, 10 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 434; Hardware p. 457

Objectives/Hypothesis

In a previous study of animals from Spacelab-3, the osteoblast appeared to be slightly smaller in size following seven days of flight. These osteoblasts were found along the endosteal surface of the diaphyseal bone and tended to have a more uniform size as compared to osteoblasts along the trabeculae in the metaphyseal region of long bones. Therefore, this study concentrated on the cells found within the diaphyseal area of long bones. The objectives here were to investigate the relationships between vascular morphology, lipid accumulation, and osteocyte and osteoblast morphology in weight-bearing long bones.

Approach or Method

Electron microscopy, light microscopy, and enzyme histochemistry were used to study the effects of space flight on metaphyseal and cortical bone of the rat tibia. Following fixation and decalcification, 50 µm thick sections were obtained with a vibratome, and sections incubated in the various media alkaline or acid phosphatase, or NADPase. Staining for lipids was carried out on frozen sections of fixed tissues and embedded vibratome sections. Morphometry was carried out on light or electron microscopy using an interactive data analysis system.

Results

Light microscopy of trabecular and cortical bone and the included osteoblast population showed no obvious morphological differences as a result of space flight. In the diaphyseal bone from flight animals, blood vessels near the periosteal surface often showed very dense intraluminal deposits. Also, in the periosteal region, many osteocytic lacunae were found devoid of osteocytes and sometimes filled an osmiophilic substance. Flight animals contained reactive saccules which averaged 11.3±6.1 saccules per cell, and the vivarium controls averaged 14.4±3.4 saccules per cell which contained reaction product. The vasculature of the flight animals was definitely less reactive than the control groups. Results of other measurements indicate that more vascular space per area of bone existed in flight animals as compared to the simulated controls. This data suggest that a vascular change may occur during flight which would then influence the bone forming ability of the osteoblasts in weight-bearing bones.

Title of Study

Gravity and Skeletal Growth: III. Nuclear Volume Analysis of Osteoblast Histogenesis in Periodontal Ligament Cells of Cosmos 1887 Rats.

Science Discipline

Musculoskeletal

Investigator	Institute
L.P. Garetto	Indiana University School of Medicine

Co-Investigator(s)	Institute
Roberts, W.E.	Indiana University School of Dentistry
Gonslaves, M.R.	NASA-Ames Research Center
Kaplansky, A.	Institute of Biomedical Problems
Durnova, G.	Institute of Biomedical Problems
Morey-Holton, E.R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

10 Flight Male

Ground-Based Controls

10 Basal, 10 Vivarium, 10 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 434; Hardware p. 457

Objectives/Hypothesis

Bone is a mechanically sensitive tissue that is particularly responsive to gravitational forces. An understanding of changes in bone mass is important since it functions not only as structural support, but also as a metabolic source of calcium. The periodontal ligament(PDL), a well defined cell kinetic model for assessing the proliferation and differentiation of the cells associated with osteoblast histogenesis, was used to study the effect on osteoblast production.

Approach or Method

PDL, the osteogenic interface between tooth and bone, was morphometrically analyzed. 3 µm sections of methyl methacrylate embedded maxillary halves were stained with hematoxylin and eosin. Only PDL samples with a resorbing (scalloped with occasional osteoclasts) or resting (no morphological evidence of active resorption or formation) alveolar bone margin were selected for analysis. Nuclear volume analysis of cells in the PDL midroot area was performed and statistically considered.

Results

Compared to synchronous controls, this flight treatment resulted in a 40% decrease in less differentiated osteoblast progenitor cells, a 42% increase in preosteoblasts (immediate precursors to osteoblasts), and increased numbers of PDL fibroblast-like cells within 25 µm of the bone surface. These results are consistent with a post-flight osteogenic response in PDL adjacent to previously resting or resorbing alveolar bone surfaces. This osteogenic response occurred despite physiological stress in the flight animals that resulted in a highly significant (p 0.001) increase in adrenal weight. The data suggest that following space flight there is a strong and rapid recovery mechanism for osteoblast differentiation that is not suppressed by physiological stress.

Title of Study

Gravity and Skeletal Growth: IV. Intervertebral Disc Swelling Pressure Associated with Microgravity

Science Discipline

Musculoskeletal

Investigator	Institute
A.R. Hargens	NASA-Ames Research Center

Co-Investigator(s)	Institute
Gott, S.A.	University of California, San Diego
Rydevik, B.	University of Goteborg, Sweden
Durnova, G.	Institute of Biomedical Problems
Morey-Holton, E.R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 434-5; Hardware p. 457

Objectives/Hypothesis

The back pain experienced by space travelers during exposure to microgravity may be caused by spinal lengthening due to swelling of their discs, a subsequent stretching of anterior and/or posterior spinal ligaments. Other work has documented that pooling of lumbar discs from the rat spine allows sufficient disc material for direct measurements of swelling pressure in this species. Therefore, studies of Cosmos 1887 rats allowed testing of the hypothesis that microgravity causes fluid uptake and decreased swelling pressure within the intervertebral disc of flight rats compared to ground-based, control rats.

Approach or Method

To examine fluid movement into discs, equilibrium swelling pressure of nucleus pulposus from flight rats was compared to controls. Measurements were made with a new compression-type osmometer that allowed direct measurement of swelling pressure.

Results

No significant differences were found in the swelling pressures between the flight and control groups of rat nucleus pulposus. Swelling pressure ranged between 622-690 mmHg. Because of the extended period between the time that the flight rats returned to Earth and the time of death (53-56 hours), it was concluded that the flight animals already were fully readapted to normal gravity in terms of fluid movement into and out of their intervertebral discs.

Title of Study

The Maturation of Bone and Dentin Matrices in Rats Flown on Cosmos 1887

Science Discipline

Musculoskeletal

Investigator	Institute
D.J. Simmons	University of Texas Medical Branch

Co-Investigator(s)	Institute
Grynpas, M.	University of Toronto
Rosenberg, G.	Indiana/Purdue University
Durnova, G.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

6 Flight Male

Ground-Based Controls

6 Basal, 6 Vivarium, 6 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 435; Hardware p. 457

Objectives/Hypothesis

Maintaining musculoskeletal integrity in astronauts during prolonged space flight is important. This concern translates to questions about the role of gravity in calcium-mediated physiological mechanisms. The particular interest here in the skeletal status of rats flown in space focuses upon the normality of the matrix and mineral moieties deposited in the bones and teeth. This report deals with the analyses of various weight and non-weight bearing bones and incisor dentin from rats.

Approach or Method

The chemistry, hydroxyapatite crystal size, and maturation of bone and dentin (utilizing the mandible, skull cap or calvarium, and 5th lumbar vertebra) were characterized, including bone ash analysis, gradient density analysis, x-ray diffraction. Analyses for calcium, phosphorus, magnesium, and zinc in bone and teeth were made on continuous traverses with a microprobe and appropriate crystal sensors.

Results

Flight calvarial and vertebral bone ash were subnormal, but contained a normal percent composition of Ca, P, and Mg. These tissues varied from the norm by having lower Ca/P and higher Ca/Mg ratios than any of their age-matched controls (Vivarium and Synchronous). Gradient density analyses (calvaria) indicated a strong shift to the lower specific gravity fractions which was commensurate with impaired rates of matrix-mineral maturation. X-ray diffraction data were confirmatory. Bone hydroxyapatite crystal growth in flight rats was preferentially altered in a way to reduce the dimension of their C-axis. Flight rat dentin was normal with respect to age-matched control Ca, P, Mg, and Zn concentrations and Ca/P and Ca/Mg ratios. These observations affirm the concept that microgravity adversely affects the maturation of newly formed matrix and mineral moieties in bone.

Title of Study

Morphometric and EM Analysis of Tibial Epiphyseal Plates From Cosmos 1887 Rats

Science Discipline

Musculoskeletal

Investigator	Institute
P.J. Duke	University of Texas Dental Branch

Co-Investigator(s)	Institute
Montufar-Solis, D.	University of Texas Dental Branch
Durnova, G.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 435; Hardware p. 457

Objectives/Hypothesis

Studies have shown that bone formation ceases during space flight, that the matrix formed during flight does not mature normally, and consequently cannot mineralize normally. The cartilagenous epiphyses of the long bones of space rats have received less attention, even though some of the changes that are seen in bone (e.g. decreased length and decreased trabecular mass) must originate in the epiphyseal region. The objectives of the present study were to look for differences in plate parameters and cell and matrix ultrastructure, in proximal tibial epiphyseal plates of space-flown rats.

Approach or Method

Light and electron microscopy studies were carried out on decalcified tibial epiphyseal plates. Height and cell number per zone and plate, shape of plates, and size of collagen fibrils were determined. A series of micrographs were taken in each zone, and measurements of collagen fibril length and width were made using a digitizing tablet. Means per section were averaged to obtain means per animal and statistical analysis was performed.

Results

Flight animals had more cells than synchronous controls in the proliferative zone, and less in the hypertrophic/calcification region. The total number of cells, however, was significantly higher in flight animals. No differences were found for perimeter or shape factor of growth plates, but area was significantly lower in flight animals in comparison to synchronous controls. Collagen fibrils in flight animals were shorter and wider than in synchronous controls. The time required for a cell to cycle through the growth plate is 2-3 days, so most of the cells and matrix present were formed after the animals had returned to 1 g, and probably represent stages of recovery from microgravity exposure.

Title of Study

Metabolic and Morphologic Properties of Muscle Fibers After Spaceflight

Science Discipline

Musculoskeletal

Investigator	Institute
V.R. Edgerton	University of California, Los Angeles

Co-Investigator(s)	Institute
Miu, B.	University of California, Los Angeles
Marini, J.	Unite de Recherches Neurobiologique
Oganov, V.S.	Institute of Biomedical Problems
Martin, T.P.	University of California, Los Angeles
Roy, R.	University of California, Los Angeles
Leger, J.J.	Unite de Recherches Neurobiologique
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 435-6; Hardware p. 457

Objectives/Hypothesis

It is apparent that a variety of biochemical and physiological properties of the rat skeleton are altered following 5-22 days of exposure to microgravity. Since these studies have been based primarily on the analysis of whole muscle properties and given the potential difference in the response of muscle fibers differing in alkaline adenosine triphosphatase (ATPase) type and size, the purposes of this study were: 1) to define the size and metabolic responses of single fibers to space flight and 2) to determine the specificity of these responses to the muscle and the myosin type and size of its fibers.

Approach or Method

The left soleus (SOL) and the medial gastrocnemius muscles were examined for ATPase fiber density, succinate dehydrogenase activity (SDH) and alpha-glycerol-phosphate dehydrogenase activity (GPD). Frozen sections of SOL were also reacted to antibodies for slow and fast myosin. Fascicles of fibers free of tissue artifact and considered visually to be representative of the tissue section were chosen for analyses. A computer assisted image analysis system was used to quantify the reaction product based on the rate of optical density for each fiber.

Results

In the SOL more fibers stained darkly with the ATPase stain in the flight than control rats. In conjunction, it appears the same fibers maintained or increased their GDP activity while maintaining their SDH activity. As a result, a greater percentage of fibers in these muscles could be categorized as fast oxidative-glycolytic. The GDP activity data suggest that some flight muscles may have an elevated capacity to utilize carbohydrate derived from carbon sources. Also, in the present data the degree of atrophy in flight muscles depended more on the muscle and the region of the muscle than on fiber type as defined by ATPase staining or the immunohistochemical properties. This differential response among muscles and muscle regions is similar to responses to hindlimb suspension. The present study demonstrates that the general capability of skeletal muscles to maintain proteins decreases rapidly in response to space flight.

Title of Study

Biochemical and Histochemical Observations of Vastus Medialis

Science Discipline

Musculoskeletal

Investigator	Institute
X.J. Musacchia	University of Louisville

Co-Investigator(s)	Institute
Steffen, J.M.	University of Louisville
Fell, R.D.	University of Louisville
Oganov, V.S.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 436; Hardware p. 457

Objectives/Hypothesis

The principal objectives of this study were to ascertain if the vastus medialis (VM) responded to microgravity exposure. Three approaches were used: 1) a histochemical evaluation of cellular morphology (fibers and capillaries); 2) an assessment of biochemical composition (protein, RNA and DNA concentrations) and 3) an estimation of metabolic activities and capacities (oxidative and glycolytic metabolism).

Approach or Method

Frozen muscle sections were stained for ATPase activity; muscle fibers and capillaries were differentiated. Fiber area and density measurements were made, and capillary distribution was assessed. The remaining samples were lyophilized, weighed, and powdered. Aliquots were used for protein; RNA and DNA concentration determinations; and for lactate dehydrogenase(LDH), citrate synthase (CS) activities, and lipoprotein lipase (LPL) activities.

Results

Although some of the morphological parameters suggest a small degree of atrophy in the VM, the biochemical analysis (protein, RNA, and DNA) suggest that these may be minimal and functionally nonsignificant. The relatively similar CS and LDH activities of VM from flight and various control groups, as well as the lack of difference between flight and synchronous rats, suggest that there is little or no effect on the oxidative or glycolytic function of this muscle. Since the VM is chiefly a mixed fast twitch muscle, these metabolic indices of energy production are relatively unchanged. The results of this study are in agreement with previous observations of another type II fast twitch muscle, the extensor digitorum longus, from Spacelab-3 rats which did not respond markedly to weightlessness and whole body suspension.

Title of Study

Morphological and Biochemical Investigations of Microgravity-Induced Nerve and Muscle Breakdown: I. Investigation of Nerve and Muscle Breakdown During Spaceflight

Science Discipline

Musculoskeletal

Investigator	Institute
D.A. Riley	Medical College of Wisconsin

Co-Investigator(s)	Institute
Ellis, S.	San Jose State University
Ilyina-Kakueva, E.	Institute of Biomedical Problems

Objectives/Hypothesis

Extended human exposure to microgravity produces progressive skeletal muscle weakness. The mechanism of the loss must be understood in order to develop rational countermeasures. While simple atrophy should be reversible by exercise, restoration of pathological changes depends upon complex processes of regeneration. This study attempted to further the understanding of the effects of space flight on muscle weakness.

Approach or Method

Rats were sacrificed two days after landing. Methods included light and electron microscopy examination of the adductor longus (AL), the extensor digitorum longus (EDL), the soleus, and plantaris muscles. Fast and slow twitch types were classified using histochemical staining properties. Ubiquitin conjugates were localized by immunostaining.

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 436; Hardware p. 457

Results

Damage was confined to the AL and soleus muscles. The midbelly region of the AL had more segmental necrosis and edema than the ends. Macrophages and neutrophils were the major mononucleated cells infiltrating and phagocytosing the cellular debris. Increased ubiquitination of disrupted myofibrils may have promoted myofilament degradation. Overall, mitochondria content and SDH activity were normal, except for a decrease in the subsarcolemmal region. The myofibril ATPase activity shifted toward the fast type in the flight AL muscles as compared to controls. About 17% of the flight AL end plates exhibited total or partial denervation. Initial signs of muscle and nerve fiber regeneration were detected. Myoblast-like cells were present in the segmental necrotic lesions cleared of cell debris, and there was a direct correlation between the distributions of hypertrophied satellite cells and segmental necrosis.

Title of Study

Morphological and Biochemical Investigations of Microgravity-Induced Nerve and Muscle Breakdown: II. Biochemical Analysis of EDL and PLT Muscles

Science Discipline

Musculoskeletal

Investigator	Institute
S. Ellis	San Jose State University

Co-Investigator(s)	Institute
Riley, D.A.	Medical College of Wisconsin
Ilyina-Kakueva, E.	Institute of Biomedical Problems

Objectives/Hypothesis

Carbonic anhydrase III (CA III) is present in highest concentrations in slow oxidative muscle fibers whereas fast fibers have very low concentrations, and the levels of the enzyme can be affected by a number of physiological perturbations. Although the plantaris (PLT) and the extensor digitorum longus (EDL) are quite gravity insensitive, it was of interest to determine the influence of space flight on levels of CA III. Conversely, parvalbumin (PVA) is highest in concentration in the fast twitch muscle and functions as a relaxing factor facilitating the sequestration of calcium in the sarcoplasmic reticulum. In view of reports that unloading slows the 1/2 relaxation time, it was also of interest to measure possible concentration decreases of this protein.

Approach or Method

Measurements were made of two enzymes, the lysosomal tripeptidyl aminopeptidase (TAP) and CA III, and also the calcium binding protein, PVA, in PLT and EDL muscles.

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 436; Hardware p. 457

Results

The PLT muscle in flight rats showed a 30% decrease in TAP; the EDL did not show a decrease in flight activity. There was no difference in CA III content of these muscles, except for the PLT of the basal group. The PVA concentrations of the PLT were not significantly different in any of the groups. In the case of EDL, only the synchronous group showed a significant reduction in PVA, whereas the basal, vivarium and flight groups did not differ. Space flight showed significant perturbation only in the TAP concentration of the PLT; the concentrations of the CA III and the PVA were unaffected in either of the two muscles. Simulation of freezer failure holding the frozen muscle showed that a thawed condition for 24 hours using fresh muscles did not result in a reduction in TAP or CA III activities, whereas PVA was reduced by 24% in the EDL and unchanged in the PLT.

Title of Study

Effects of Zero Gravity on Myofibril Protein Content and Isomyosin Distribution in Rodent Skeletal Muscle

Science Discipline

Musculoskeletal

Investigator	Institute
K.M. Baldwin	University of California, Irvine

Co-Investigator(s)	Institute
Herrick, R.	University of California, Irvine
Oganov, V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 436-7; Hardware p. 457

Objectives/Hypothesis

The purpose of this experiment was to investigate the effects of twelve days of microgravity exposure on the enzymatic properties, protein content, and isomyosin distribution of the myofibril fraction of the slow-twitch vastus intermedius (VI) and the fast-twitch vastus lateralis (VL) muscles of adult male rats. The study tested the general hypothesis that zero gravity would induce: 1) a preferential loss of slow myosin and a corresponding increase in myofibril ATPase activity in the VI and 2) minimal changes in the VL.

Approach or Method

Myofibrils extracted from the VI and the VL were analyzed using electrophoresis and a soft laser scanning densitometer. Myofibril ATPase specific activity was determined at a free calcium concentration with the use of a buffer system. Both the flight and ground control groups were examined for muscle mass, myofibril protein content and ATPase specific activity, and estimates of absolute and relative isomyosin content.

Results

The results were largely in support of the hypothesis. Compared to the two control groups, VI weight was lower by 23% ($p < 0.10$); whereas no such reduction was observed for the VL muscle. No evidence of loss of the fast isomyosins was apparent for either muscle following space flight. Myofibril ATPase activity of the VI was increased in the flight group compared to the controls, which is consistent with the observation of preferential slow-myosin degradation. These data suggest that muscles containing a high percent of slow twitch muscle fibers undergo greater degrees of myofibril protein degradation than do muscles containing predominantly fast twitch fibers in response to a relatively short period of microgravity exposure, and the primary target appears to be the slow-myosin molecule. This observation is consistent with previous findings on the soleus muscle of hindlimb suspended rats, further suggesting that the absence of ground support activity is an important factor in inducing the atrophy response.

Title of Study

Actin mRNA and Cytochrome-C mRNA Concentrations in the Triceps Brachia Muscle of Rats

Science Discipline

Musculoskeletal

Investigator	Institute
F.W. Booth	University of Texas Medical School, Houston

Co-Investigator(s)	Institute
Morrison, P.R.	University of Texas Medical School
Thomason, D.B.	University of Texas Medical School
Oganov, V.S.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 437; Hardware p. 457

Objectives/Hypothesis

Some skeletal muscles atrophy as a result of weightlessness and as a result of hindlimb suspension. The content of protein is determined by the rate of protein synthesis and degradation. Any decrease in protein synthesis could be caused by decreases in mRNA concentrations. In suspended rat hindlimbs, an increased protein degradation and a decreased protein synthesis were observed, as well as decreases in the concentration and content of alpha-actin mRNA and cytochrome-C mRNA. From these findings, it was hypothesized that the same pattern could be observed in the triceps brachia muscle of space-flown rats.

Approach or Method

Relevant determinations included muscle wet weight, RNA concentration, RNA content, alpha-actin mRNA concentration, and cytochrome-C mRNA concentration. Variance was determined by ANOVA.

Results

The triceps brachia was not atrophied after 42 hours recovery from the 12.5-day flight. Both of these factors (lack of atrophy and delayed recovery time) likely contributed to the lack of change in RNA content and alpha-actin mRNA concentration per unit of RNA. Rapid recovery of alpha-actin mRNA concentrations has been noted in atrophied muscle recovering from seven days of hindlimb immobilization. It is also possible to speculate that the triceps brachia was recruited frequently in space, as the rat attempted to hold on to a position in the cage or move between two points, and that this prevented atrophy. The failure to observe a significant decrease in cytochrome-C mRNA was likely related either to the absence of atrophy or to a speculated absence of a decline in the electromyographic activity of the triceps brachia muscle. It is unlikely that the recovery period was the explanation for this, since cytochrome-C mRNA did not recover for the first two days after seven days of limb immobilization.

Title of Study
Analysis of Radiographs and Biosamples from Primate Studies

Science Discipline
Musculoskeletal

Investigator	Institute
C.E. Cann	University of California, San Francisco

Co-Investigator(s)	Institute
Rakhmanov, A.	Institute of Biomedical Problems
Korolkov, V.I.	Institute of Biomedical Problems

Research Subject(s)
Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls
4 Synchronous

Key Flight Hardware
Cosmos 1887 Russian Hardware Suite

More Information
Mission p. 156-61; Publications p. 437; Hardware p. 457

Objectives/Hypothesis
The present experiment was designed to serially study the growth and development of the juvenile primate peripheral skeleton, and to determine if a two-week period of space flight affected this development. This design was chosen because in the juvenile primate (3-5 kg), the skeleton is still undergoing rapid development at this stage, with longitudinal growth at the unfused metaphyseal-epiphyseal junctions, and periosteal and endosteal architectural modeling. This provides the possibility to detect an effect of microgravity by a change in the normal rate of growth and modeling.

Approach or Method
Serial high-contrast radiographs were obtained of both arms and the right leg of two flight and four control monkeys. This investigation included a significant amount of preflight testing and development of optimal radiograph techniques in the U.S.S.R. Serial radiographs were taken of flight candidate, flight, and control monkeys from a period sixty days prior to launch to two weeks after the postflight control (synchronous) experiment.

Results
Longitudinal growth of the tibia, radius, and ulna was linear over this period in the control monkeys. In the flight monkey for whom the feeder malfunctioned, there were significant decreases in growth of long bones. There were also hypermineralized growth arrest lines produced in the distal radial and ulnar metaphyses following resumption of growth. In the other flight monkey, there was a suggestion of decreased long bone growth during flight and immediate postflight periods, but this recovered by the end of the postflight control experiment. There was also an increase in intracortical resorption, indicative of skeletal activation. No major changes in cortical thickness or other parameters were noted, but modifications of the techniques to obtain very high quality radiographs in further studies should allow subtle changes in these processes to be quantified.

Title of Study

Study of Muscarinic and GABA (Benzodiazepine) Receptors in the Sensory-Motor Cortex, Hippocampus, and Spinal Cord

Science Discipline

Neuroscience

Investigator	Institute
N.G. Daunton	NASA-Ames Research Center

Co-Investigator(s)	Institute
D'Amelio, F.	NASA-Ames Research Center
Krasnov, I.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

2 Flight Male

Ground-Based Controls

2 Vivarium, 2 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 437; Hardware p. 457

Objectives/Hypothesis

In this experiment, frontal lobe samples from brains of space-flown rats were processed for the study of muscarinic (cholinergic) and GABA (benzodiazepine) receptors, and for immunocytochemical localization of the neurotransmitter gamma-aminobutyric acid (GABA) and glial fibrillary acidic protein (GFAP). The aim was to explore the feasibility of investigating neurotransmitters and their receptors in space flight experiments.

Approach or Method

For receptor binding studies, slides with 20 µm frontal lobe sections were incubated with ^{3}H-ligand, washed, and later placed in an x-ray cassette. Tritium sensitive film was placed over the slides and later developed. For GABA and GFAP immunocytochemistry, slide-mounted tissue sections were fixated with appropriate solutions and rinsed in cold phosphate buffer saline.

Results

Although radioactive labeling of both muscarinic cholinergic and GABA receptors proved to be successful with the techniques employed, distinct receptor localization of individual laminae of the frontal neocortex was not possible since the sampling area was different in the various groups of animals. In spite of efforts made for proper orientation and regional identification of laminae, it was found that a densitometric (quantitation of autoradiograms) analysis of tissue did not contribute to the final interpretation of the effects of weightlessness on these receptors. As to the immunocytochemical studies, the use of both markers, GFAP and GABA antiserum, confirmed the suitability of the techniques for frozen material. Similar problems to those encountered in the receptor studies prevented an adequate interpretation of the effects of microgravity exposure on the localization and distribution of GABA and GFAP.

Title of Study

Radiation Dosimetry and Spectrometry

Science Discipline

Radiation/Environmental Health

Investigator	Institute
E.V. Benton	University of San Francisco

Co-Investigator(s)	Institute
Frank, A.	University of San Francisco
Dudkin, V.	Institute of Biomedical Problems
Marennyi, A.M.	Institute of Biomedical Problems
Benton, E.R.	University of San Francisco

Research Subject(s)

Not Applicable

Ground-Based Controls

Not Applicable

Key Flight Hardware

Radiation Detectors: Cosmos 1887 Radiation Dosimeters

More Information

Mission p. 156-61; Publications p. 437; Hardware p. 532-3

Objectives/Hypothesis

Radiation experiments flown on the Cosmos 1887 spacecraft were designed to measure the depth dependence of both total dose and heavy particle flux, dose and dose equivalent, down to very thin shielding. The objectives of these experiments were: 1) to measure radiation inside the spacecraft; 2) to measure the depth dose under very thin shielding on the outside of the spacecraft and determine what fraction of the dose was due to low energy electrons versus heavy charged particles; and 3) to determine the low energy, heavy particle (excluding electrons) LET spectra under essentially zero shielding (outside the spacecraft) and as a function of depth, and to obtain some information on the neutron energy spectra.

Approach or Method

Five plastic nuclear track detector (PNTD) stacks were used to measure heavy-particle, high LET spectra; a nuclear emulsion stack was included to measure the energetic proton spectrum; and thermoluminescent detectors (TLDs) were used to measure the total dose. Two identical flight units consisting of aluminum cylinders of 5 cm diameter and 1.99 cm thickness with cylindrical holes to accommodate TLD stacks were used for shielding depth-dose measurements. Two hermetically sealed canisters with thin plastic windows and containing PNTD stacks were used to measure LET spectra under low shielding outside the spacecraft. TLDs and PNTDs were also placed in a plastic box inside the spacecraft. For neutron measurements, ^{59}Co activation foils were placed both inside and outside the spacecraft.

Results

Total absorbed dose rates varied from 264 to 0.028 rad d^{-1} under shielding of 0.013 to 3.4 g/cm^{-2} of ^{7}LiF outside the spacecraft and 0.0025 ± 0.001 rad d^{-1} inside the spacecraft. The measurements of high LET particles show particle fluxes up to 3.43 x 10^{-3} cm^{-2} s^{-1} sr^{-1} outside the spacecraft and 4.25 x 10^{-4} cm^{-2} s^{-1} sr^{-1} inside. High LET dose rates and dose equivalent rates up to 5.25 mrad d^{-1} and 30.8 mrem d^{-1} were obtained outside the spacecraft, and rates of 1.27 mrad d^{-1} and 11.4 mrem d^{-1} were found inside. Because of damage to the least shielded CR-39 PNTD, the maximum levels of high LET particles were not obtained. In comparing the depth dose measurements with calculations (alt. 300 km, incl., 62°) of depth dose in an infinite slab-geometry, including e-, p, GCR, and bremsstrahlung, the experiment shows a factor of ~44 decrease in the first 0.1 g/cm^{-2} of ^{7}LiF, while calculations show a decrease by a factor of 28.5 in the first 0.1 g/cm^{-2} of Al.

Title of Study
Trace Element Balance in Rats During Spaceflight

Science Discipline
Regulatory Physiology

Investigator	Institute
C.E. Cann	University of California, San Francisco

Co-Investigator(s)	Institute
Patterson-Buckendahl, P.	University of California, San Francisco
Durnova, G.	Institute of Biomedical Problems

Research Subject(s)
Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls
5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware
Cosmos 1887 Russian Hardware Suite

More Information
Mission p. 156-61; Publications p. 438; Hardware p. 457

Objectives/Hypothesis
Little is known about the effects of space flight in an older skeleton. Limited data suggest that bone resorption is increased after five days, but no data are available about other metabolic effects. The response of a more slowly growing skeleton may be different than that of a younger animal, similar to the different responses seen in adolescents and adult humans to immobilization. This experiment was designed to investigate changes occurring in skeletal and mineral homeostasis in older, space-flown rats.

Approach or Method
Vertebral specimens from flight and synchronous, vivarium, and basal control rats were obtained for analysis. Selected vertebrae (fourth lumbar), were weighed, separated into four parts, lyophilized to constant weight, then ground to a fine powder. Osteocalcin was measured in extracts of the powder with a rat-specific osteocalcin assay. Calcium was measured using atomic absorption spectrophotometry, and phosphorus was determined using a modified Fiske-Subarow method. In addition, a pooled excreta collection and samples of the flight paste diet were analyzed.

Results
The differences between flight and control animals were minimal. Mass of the whole vertebrae increased 6.2% in synchronous rats compared to less than 2% when compared to basal controls, suggesting a decreased rate of bone growth in flight. The increased osteocalcin concentration in the posterior spine of flight rats, as compared to all controls, suggests a higher state of maturation of this compact bone, possibly due to a slowed turnover with the removal of both dorsal-to-ventral loading as well as torsional muscle pulls in space flight. This is similar to differential effects of long-term microgravity exposure seen in the vertebral body and posterior elements in cosmonauts.

Title of Study

Morphometric Studies of Atrial Granules and Hepatocytes: I. Morphometric Study of the Liver

Science Discipline

Regulatory Physiology

Investigator	Institute
L.M. Kraft	NASA-Ames Research Center

Co-Investigator(s)	Institute
Popova, I.A.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 438; Hardware p. 457

Objectives/Hypothesis

The goal of the present study was to characterize the vacuoles, to obtain data with which to evaluate the gross and microscopic differences, and, if possible, to explain the increased liver weight of the flight group from microscopic morphometric findings. In addition to the use of general histological techniques, morphology of the hepatocyte nuclei and intracytoplasmic vacuoles was undertaken using light microscopic computer assisted image analysis.

Approach or Method

Light microscopic computer assisted morphometry was performed with an image analysis system of the hepatocyte nuclei and intracytoplasmic vacuoles of rat liver. Nuclei in 25 fields of view were measured in stained 4 µm embedded sections. Care was taken to include representative fields from all lobular regions. These were selected at random but were included only if scanning indicated that fixation was adequate. To ascertain the relationship between the increase in liver weight of flight animals and the results of this study, an assumption was made that the specific gravity of the vacuolar contents was similar to that of the other extranuclear components of the hepatocyte.

Results

On that basis, calculations showed that the elevated vacuolar volume density in the flight group did not cause the increased liver weight in those animals, but that the non-nuclear, non-vacuolar parenchymal compartment did contribute significantly. Since only rare vacuoles were stained in all groups, severe glycogenic infiltration was regarded as the most likely cause of the pale appearance of the flight livers. Supporting this conclusion is the fact that glycogen would have been dissolved in the aqueous fluids used in processing, leaving empty spaces such as those seen in preparations. Regardless of the correctness of these assumptions, there is little doubt that changes in nuclear and vacuolar components were only minor contributors to the increased liver weight of the flight animals, while the remainder of the hepatocytic cytoplasm contributed the major portion of the increase.

Title of Study

Morphometric Studies of Atrial Granules and Hepatocytes: II. Atrial Granular Accumulations

Science Discipline

Regulatory Physiology

Investigator	Institute
L.M. Kraft	NASA-Ames Research Center

Co-Investigator(s)	Institute
Keil, L.C.	NASA-Ames Research Center
Popova, I.A.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 438; Hardware p. 457

Objectives/Hypothesis

Since electrolyte imbalance and fluid shifts have been experienced by humans (and animals) during space flight, it seemed appropriate to examine the atrial natriuretic factor (ANF) granulated regions in the atria of rats from the Cosmos 1887 flight, and to ascertain, by means of morphometric and stereological methods, if quantitative changes occurred in flight animals.

Approach or Method

Light microscopic computer assisted morphometry of the atria was performed with an image analysis system. To make measurements for the area and perimeter, an editing function was used to outline the granular regions projected on the image monitor; because the reference area did not always fill the monitored field, the same method was used to delineate the pertinent reference regions when necessary. From values for object (granular accumulation) area, object perimeter, and reference field area, the stereology program calculated volume density and mean volume of the objects. Numerical density was calculated as the number of objects per unit reference area $x10^3$.

Results

Those of the flight group had a significantly greater volume density than the synchronous or vivarium control groups, while the controls did not differ in this respect. The number of granular accumulations per unit reference area was also increased in flight animals. Mean volume on the individual granulated regions did not differ among the three groups. The increase in the flight group was therefore due to an increase in the number of granular regions rather than their size. No differences were seen between right and left atria of any groups. Likely causes for the increase in volume density of the granular regions in the flight group include reduced blood volume and/or body water content, but an exhaustive attempt to interpret these findings in terms of physiological importance would be speculative, especially because no chemical determinations of ANF were made.

Title of Study

Hepatic Function in Rats After Spaceflight

Science Discipline

Regulatory Physiology

Investigator	Institute
A.H. Merrill	Emory University School of Medicine

Co-Investigator(s)	Institute
Hoel, M.	Emory University School of Medicine
Hargrove, J.	Emory University School of Medicine
Popova, I.A.	Institute of Biomedical Problems
Wang, E.	Emory University School of Medicine
Jones, D.	Emory University School of Medicine
Mullins, R.	Emory University School of Medicine

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 438; Hardware p. 457

Objectives/Hypothesis

Among the changes that have been observed during and after space flight are elevated adrenal steroid secretion and altered concentrations of various lipids and carbohydrates in blood and other tissues. Since the liver is an important site of nutrient and xenobiotic metabolism, further study of the effects of space flight on this organ appear warranted. Based on previous findings, it was proposed that several aspects of hepatic function are altered by space flight. In particular, these include key enzymes of cholesterol and sphingolipid biosynthesis and drug metabolism (e.g. cytochrome P-450). This study was to provide additional data from analyses of liver and serum samples from space-flown rats that support this hypothesis.

Approach or Method

To determine the possible biochemical consequences of prolonged weightlessness on liver function, tissue samples from flight and control rat were analyzed for hepatic protein, glycogen, and lipids as well as the activities of a number of key enzymes involved in metabolism of these compounds and xenobiotics.

Results

Among the parameters measured, the major differences were elevations in the hepatic glycogen content and HMG-CoA reductase activities of the flight rats, and a decrease in the amount of microsomal cytochrome P-450 and the activity of aniline hydroxylase, a cytochrome P-450-dependent enzyme. Decreases in these two indices of the microsomal mixed-function oxidase system indicate that space flight may compromise the ability of liver to metabolize drugs and toxins. The higher HMG-CoA reductase correlated with elevated levels of serum cholesterol. Other changes included somewhat higher blood glucose, creatinine, SGOT, and much greater alkaline phosphatase and BUN. These results generally support the earlier observation of changes in these parameters. The importance of these alterations is not known; however, they have the potential to complicate long-term space flight.

Title of Study

The Effect of Cosmos 1887 Flight on Spermatogonial Population and Testosterone Level in Rat Testes

Science Discipline

Regulatory Physiology

Investigator	Institute
D.E. Philpott	NASA-Ames Research Center

Co-Investigator(s)	Institute
Kato, K.	NASA-Ames Research Center
Sapp, W.	Tuskegee University
Popova, I.A.	Institute of Biomedical Problems
Stevenson, J.	NASA-Ames Research Center
Vasques, M.	NASA-Ames Research Center
Williams, C.	Tuskegee University
Serova, L.V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 438; Hardware p. 457

Objectives/Hypothesis

Immobilization, applied for a short or long period, is considered a form of physiological stress. Most reports indicate that stress decreases testosterone levels, but does not cause any morphological changes in the seminiferous tubules. On the other hand, irradiation, depending on the dosage, can result in the depletion of all spermatogonial cells except a few stem cells, while testosterone levels do not seem to be affected either in serum or intratesticular tissue. This experiment was to further understand space flight effects on the testes.

Approach or Method

The left and right testes provided material for weight determination, testosterone assay, and spermatogonial cell loss quantification. Two-micron cross sections were cut on an ultramicrotome. Alternate sections containing maturation stage six were used to count surviving spermatogonial cells. Testosterone measurements were made on the rat plasma samples.

Results

When the mean weights of the flight testes, normalized for weight of 100 g, were compared to the vivarium controls, they were 6.7% lighter; although the difference was not significant. Counts of spermatogonial cells from five animals in each group revealed a 4% decrease in flight compared to vivarium controls. In both cases the t-test significance was $0 < 0.02$. The serum testosterone levels of all animals (flight, synchronous, and vivarium) were significantly below the basal controls. Stress-related gonadal dysfunction and possible galactic radiation exposure, along with other possible factors, apparently contribute to the significant decrease in spermatogonial cell numbers observed in rats flown in space.

Title of Study

Structural Changes and Cell Turnover in the Rat's Small Intestine Induced by Spaceflight

Science Discipline

Regulatory Physiology

Investigator	Institute
R.W. Phillips	Colorado State University

Co-Investigator(s)	Institute
Sawyer, H.R.	Colorado Sate University
Smirnov, K.V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 438-9; Hardware p. 457

Objectives/Hypothesis

The purpose of this study was to test the hypothesis that the generalized, whole-body decrease in synthetic activity associated with microgravity conditions of space flight as evidenced by negative nitrogen balance and muscle atrophy, as well as inhibited lymphocyte proliferation, would be evident in cells characterized by a rapid rate of turnover. As a model it was decided to study the turnover of mucosal cells lining the jejunum of the small intestine, since these cells are among the most rapidly proliferating in the body.

Approach or Method

The mitotic index was determined for mucosal cells lining the proximal, middle, and distal regions of the jejunum in rats from three treatment groups (synchronous control, vivarium control, and flight); the depth of the crypts of Lieberkuhn was measured; and the length of villi present in each of the three jejunal regions sampled. To accurately determine the mitotic index for each region, at least 2,000 cells per region per animal were examined. Prior to evaluation all slides were coded so that the technician reading the slides did not know the region or treatment group being examined. To determine villus length and crypt depth at least 25 villi and crypts per region per animal were measured, using a computerized image analysis system coupled to a bright field microscope.

Results

The number of mitotic figures observed in the proximal jejunum of the flight animals was higher compared to either the synchronous or vivarium animals. Conversely, in the middle and distal jejunum, both the synchronous controls and flight animals had an increased number of mitotic figures compared to vivarium controls. The height of jejunal villi in flight animals was not significantly different from that observed in animals included in the synchronous or vivarium groups. With respect to region by treatment interactions, the only marked difference was that the crypt depth in the proximal jejunal region in the flight animals was less than that measured in the synchronous animals. However, since there were no consistent differences between animals in the flight group and those in synchronous and vivarium control groups, it appears that any effects of microgravity on the turnover of jejunal mucosal cells were short-lived and rapidly returned to normal.

Title of Study

Pineal Physiology in Microgravity: Relation to Rat Gonadal Function

Science Discipline

Regulatory Physiology

Investigator	Institute
D. Holley	San Jose State University

Co-Investigator(s)	Institute
Soliman, M.R.I.	Florida A & M University
Markley, C.	San Jose State University
Krasnov, I.	Institute of Biomedical Problems
Kaddis, F.	Florida A & M University

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 439; Hardware p. 457

Objectives/Hypothesis

It is now known that the pineal organ can interact with many endocrine and non-endocrine tissues in a regulatory fashion. In view of the fact that the pineal is an important link to the environment, it is conceivable that exposure to microgravity and space flight might alter the function of this gland and, in turn, affect the various physiological functions including the circadian timing system. Given the link between exposure to microgravity and perturbation of calcium metabolism, and the fact that the pineal is apparently one of the only "soft tissues" to calcify, this study examined pineal calcium content following space flight.

Approach or Method

Given its key role in the regulation of melatonin synthesis, its high concentration, and the fact that its levels may persist longer than the more rapidly changing melatonin, it was thought that serotonin might give a more accurate assessment of the effects of microgravity on pineal function. 5-hydroxyindole acetic acid (5-HIAA), a major metabolite of serotonin, was also measured. Serotonin and 5-HIAA were analyzed in the filtered homogenates by HPLC; melatonin content was determined by radioimmunoassay. Total calcium content of the pineal homogenates was determined by atomic absorption spectrophotometry using an electrothermal atomizer equipped with a carbon rod.

Results

Pineal melatonin content for individual glands showed no significant differences among the three test groups as determined by one-way analysis of variance. Serotonin and 5-HIAA content results from two animals (one flight and one synchronous) were considerably different from other values within their respective groups. If the two values are removed from the analysis, then both flight group serotonin and 5-HIAA are significantly greater than controls. The plasma concentration of 5-HIAA in all groups was below the detectable sensitivity of the HPLC machine used in the analysis, which indicates the plasma concentrations were less than 2.0 ng/ml. One-way analysis of variance of calcium determinations indicated no statistical differences among groups. In summary, it was concluded that the space flight resulted in a stress response as indicated by adrenal hypertrophy, that gonadal function was compromised, and that the pineal may be linked as part of the mechanisms of the responses noted.

Title of Study

The Effect of Spaceflight on Pituitary Oxytocin and Vasopressin Content of Rats

Science Discipline

Regulatory Physiology

Investigator	Institute
L.C. Keil	NASA-Ames Research Center

Co-Investigator(s)	Institute
Evans, J.	NASA-Ames Research Center
Grindeland, R.	NASA-Ames Research Center
Krasnov, I.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

10 Flight Male

Ground-Based Controls

10 Basal, 10 Vivarium, 10 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 439; Hardware p. 457

Objectives/Hypothesis

Disturbances in fluid and electrolyte balance have been noted in humans exposed to space flight. Similar postflight fluid-electrolyte and hormone responses have been observed in rats that were exposed to microgravity. Microscopic examination of the hypothalamus and posterior pituitary gland of flight rats exposed to space flight shows changes indicative of increased activity (e.g. increased hormone synthesis and secretion). The purpose of this investigation was to measure levels of pituitary oxytocin (OT) and vasopressin (AVP) as possible indicators of changes in fluid-electrolyte balance during space flight.

Approach or Method

Pituitary levels of OT and AVP were measured in space-flown rats and ground-based controls. An aliquot of the homogenate was diluted 1:200,000 in 0.5M phosphate assay buffer for radioimmunoassay of OT and AVP. After the hormone levels were determined, protein concentrations were measured in aliquots from each homogenate, and then calculated as a function of total protein for each posterior pituitary homogenate.

Results

Both neural lobe hormone levels were significantly reduced in the flight animals when compared to either set of controls. When expressed in terms of pituitary protein content, the results still indicate a significant reduction in pituitary OT and AVP compared to either control group by both parametric and nonparametric tests. Pituitary OT in the flight group was 33.6% lower compared to synchronous controls and 37.3% lower than vivarium controls. Pituitary AVP was 20.7% lower in the flight group compared to that in synchronous controls, and 29.2% lower than in vivarium controls. The reduced levels of pituitary OT and AVP may have resulted from the combined effects of water deprivation (during re-entry) and the stress of the novel microgravity environment. The flight animals were dehydrated, and this led to a significant reduction in both pituitary OT and AVP. Results also show that pituitary OT was reduced to a greater extent than AVP, and perhaps this decrease was in response to increased stress or motion sickness encounter during flight and/or recovery.

Title of Study

Effect of Microgravity on: I. Metabolic Enzymes of Individual Muscle Fibers

Science Discipline

Regulatory Physiology

Investigator	Institute
O. Lowry	Washington University School of Medicine, St. Louis

Co-Investigator(s)	Institute
McDougall, Jr., D.	Washington University, St. Louis
Carter, J.	Washington University, St. Louis
Krasnov, I.	Institute of Biomedical Problems
Nemeth, P.M.	Washington University, St. Louis
M.-Y. Chi, M.	Washington University, St. Louis
Manchester, J.	Washington University, St. Louis
Pusateri, M.E.	Washington University, St. Louis
Norris, B.	Washington University, St. Louis

Research Subject(s)

Rattus norvegicus (Wistar Rat)

2 Flight Male

Ground-Based Controls

2 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 439; Hardware p. 457

Objectives/Hypothesis

The individual fibers of any muscle vary greatly in enzyme composition, a fact which is obscured when enzyme levels of a whole muscle are measured. The purpose of this study was, therefore, to assess the changes due to weightlessness on the enzyme patterns composed by the individual fibers within the muscles of rats subjected to space flight.

Approach or Method

Studies were made on 64 soleus (slow-twitch) and 164 tibialis anterior (fast-twitch) fibers from two synchronous and two flight animals. Each fiber was analyzed in duplicate for two to eight different enzymes, and the size (µg/mm) determined, involving more than 2,300 quantitative measurements. Since each assay required only 0.1 to 0.2 µl of extract (equivalent to 10-20 ng of dry fiber), a single 5 µl extract was sufficient for duplicate assays on a large number of different enzymes.

Results

The average size (weight per unit length) was about 35% lower in flight than in synchronous muscles of both types (fast and slow twitch). In the soleus muscle, the only conclusive enzyme change was in hexokinase which increased an average of 137% on the dry weight basis. In the tibialis anterior (TA) muscles, hexokinase increased about the same percentage as in the soleus, but in addition all the enzymes of oxidative metabolism were increased about 60%. The glycolytic, glycogenolytic enzymes in TA, in contrast to the soleus muscles were all somewhat lower (12%-25%) in the flight muscles. In contrast, on a fiber length basis, it is apparent that although hexokinase increased in absolute terms, the increase was no more than 50%, and that six of the enzymes decreased by 10% to 40%. Similarly in the TA muscle, whereas in absolute terms (fiber length basis) oxidative enzymes were almost unchanged, hexokinase increased, but only by 25%, and phosphorylase and the glycolytic enzymes decreased about 50%.

Title of Study

Effect of Microgravity on: II. Metabolic Enzymes of Hippocampus and Spinal Cord

Science Discipline

Neuroscience

Investigator	Institute
O. Lowry	Washington University School of Medicine, St. Louis

Co-Investigator(s)	Institute
McDougall, Jr., D.	Washington University, St. Louis
Carter, J.	Washington University, St. Louis
Krasnov, I.	Institute of Biomedical Problems
Nemeth, P.M.	Washington University, St. Louis
M.-Y. Chi, M.	Washington University, St. Louis
Manchester, J.	Washington University, St. Louis
Pusateri, M.E.	Washington University, St. Louis
Norris, B.	Washington University, St. Louis

Research Subject(s)

Rattus norvegicus (Wistar Rat)

3 Flight Male

Ground-Based Controls

2 Vivarium, 1 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 439; Hardware p. 457

Objectives/Hypothesis

The question of possible enzyme changes due to exposure to microgravity is much more complicated in the case of the central nervous system than it is for skeletal muscle. The brain is enormously complex. Valid comparisons must be made between exactly the same regions of control and flight brains, otherwise natural differences will confuse the issue. This study compares flight and synchronous enzymes from the hippocampus and spinal cord with regards to specific regions.

Approach or Method

Nine different enzymes in six regions of the hippocampus, and four and five enzymes in five regions of the spinal cord (a total of almost 500 quantitative measurements) were measured in two vivarium and two flight animals. Whenever possible, the assays for a number of enzymes were in duplicate with aliquots from an extract of a single, relatively large tissue sample. The spinal cord data was limited to one (synchronous) control and one flight animal.

Results

The six enzymes of the hippocampus were in most cases remarkably similar in flight and control (vivarium) brains. ß-hydroxyacyl CoA dehydrogenase was 35% lower in the molecular layer of CA1 of the flight brain; however, the other two enzymes of oxidative metabolism in this region were within 10% of the control. The glutamate decarboxylase activities were quite variable, nevertheless it probably should not be ignored that levels for the flight samples from all of the hippocampal regions were on the average 30% higher than controls. For glutaminase, in CA1 average values for the three regions assayed were 25% to 59% higher in flight than control tissue. For the spinal cord, the higher aspartate aminotransferase values for the pyramidal tract and outer dorsal horn, and lower glutaminase levels in the dorsal column and pyramidal tract of the flight animal, would be worth further investigation.

Title of Study

Growth Hormone Regulation, Synthesis, and Secretion in Microgravity: I. Somatotroph Physiology

Science Discipline

Regulatory Physiology

Investigator	Institute
R.E. Grindeland	NASA-Ames Research Center

Co-Investigator(s)	Institute
Hymer, W.	Pennsylvania State University
Kaplansky, A.	Institute of Biomedical Problems
Victorov, I.	Brain Research Institute, Moscow
Krasnov, I.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

10 Vivarium, 5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 439; Hardware p. 457

Objectives/Hypothesis

Since the pituitary growth hormone (GH) controls the activity of both muscle and bone, effects of space flight on GH cell function have received some attention. Taken together, results suggested that GH cells from flight animals had experienced a partial shutdown in hormone secretion. The overall objective of this experiment was to determine if results from the SL-3 experiment were repeatable. Additionally, this study was to extend the earlier findings in light of the longer duration of flight. Finally, the design of the methodology was modified to permit statistical analysis of the GH secretion data.

Approach or Method

The design of this study was dictated by the following considerations: five pituitary glands were available for study; ~2 x 1,000,000 cells could be prepared from each gland; and a number of structure function tests, each requiring different numbers of cells, was possible. In order to accomplish experimental goals, some cells from each gland were cultured individually while the remaining cells from each gland were then pooled with others from the same treatment groups for subsequent morphological analyses and transplantation study.

Results

The percentages of GH cells prepared from glands in the different groups, based on counts of 50,000 cells/treatment group, did not differ. However, the staining intensity of the GH cells in the flight group was two times greater than that of cells in the synchronous group. The increased intensity of specific cytoplasmic GH fluorescence was also documented by the morphological appearance of cells. These results suggest, but do not prove, that there was more GH/cell in the flight group. Cell culture data revealed that: 1) levels of secreted GH were, in the case of serumless medium, ~70% of those in serum-containing medium; 2) relative to the first three-day culture period, levels of hormone in the synchronous group were two to three times greater during the second three-day culture period; and 3) flight cells did not show the same corresponding increase in iGH during the second three-day period. Results support the contention that there is a secretory lesion in pituitary GH cells of flight animals.

Title of Study

Growth Hormone Regulation, Synthesis, and Secretion in Microgravity: II. Immunohistochemical Analysis of Hypothalamic Hormones

Science Discipline

Regulatory Physiology

Investigator	Institute
W. Vale	The Salk Institute, La Jolla

Co-Investigator(s)	Institute
Sawchenko, P.	Salk Institute
Krasnov, I.	Institute of Biomedical Problems
Grindeland, R.E.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 439-40; Hardware p. 457

Objectives/Hypothesis

It was originally anticipated that, for this experiment, blocks of hypothalamic tissue would be prepared for radioimmunoassay of hypophysiotropic hormones mediating somatic growth (growth hormone-releasing factor, somatostatin) and stress-related corticotropin secretion (corticotropin-releasing factor). Even within the hypothalamus, however, each is also rather broadly distributed in cell bodies and/or axons that bear no ostensible relationship to their hypophysiotropic functions. Because of this, it was decided to attempt to employ immunohistochemical methods to better localize effects of space flight on these neuropeptide systems.

Approach or Method

The fixation protocol employed was based on preliminary studies in which investigators attempted to maximize antigenicity and morphologic preservation in fresh frozen samples. A conventional indirect immunofluorescence method was used for staining. Complete series of sections through the hypothalamus of each member of the flight and synchronous group were incubated in primary antisera. All primary antisera were localized with an affinity purified, fluorescein-conjugated, goat anti-rabbit IgG.

Results

In summary, consistently lesser staining intensities for both somatostatin-28 and growth hormone-releasing factor were observed in flight tissues, relative to synchronous controls. No such alterations were noted in staining for arginine vasopressin and corticotropin-releasing factor. The fact that staining for both of the principles involved most directly in the central regulation of growth hormone secretion appeared to be affected somewhat selectively may suggest a specific neuroendocrine dysfunction within the central nervous system. The sub-optimal fixation protocol, and the (presumably associated) diffuse staining of fibers and terminals in the median eminence, must temper any interpretation of this data. Finally, the fact that both the stimulatory and inhibitory principles appear driven in the same direction is perplexing, and could represent a compensatory or counter-regulatory response of one system to a perturbation in the other.

Title of Study

Growth Hormone Regulation, Synthesis, and Secretion in Microgravity: III. Plasma Analysis

Science Discipline

Regulatory Physiology

Investigator	Institute
R.E. Grindeland	NASA-Ames Research Center

Co-Investigator(s)	Institute
Popova, I.	Institute of Biomedical Problems
Vasques, M.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

10 Flight Male

Ground-Based Controls

10 Basal, 10 Vivarium, 10 Synchronous

Key Flight Hardware

Cosmos 1887 Russian Hardware Suite

More Information

Mission p. 156-61; Publications p. 439-40; Hardware p. 457

Objectives/Hypothesis

Plasma hormone and biochemical analyses were performed either at NASA-Ames or by a clinical laboratory. Results of these tests were made available to all U.S. investigators to facilitate their evaluation of animal physiological status and interpretation of their data. For example, phosphorus, calcium, and alkaline phosphatase values are considered with bone studies; plasma proteins and albumin concentrations are discussed with the liver enzyme studies; and testosterone titers are discussed with the testes and pineal gland investigations.

Approach or Method

Trunk blood was collected after decapitation into tubes containing 50 ml ammonium heparin. Blood biochemical measurements were determined in automated analysis. Plasma immunoactive growth hormone was determined in-house by radioimmunoassay. Testosterone and corticosterone were assayed using immunoassay kits.

Results

The increased plasma glucose concentration in flight rats appears to be a response to microgravity, but the mechanisms are uncertain. Plasma calcium was lower in flight than in vivarium or basal rats, but not different from synchronous rats, suggesting a dietary regimen or caging effect. In contrast, phosphorus concentrations were higher in flight than synchronous animals, similar to those of vivarium and less than those of basal. Alkaline phosphate values were 50% higher in the flight animals than synchronous controls, consistent with changes in bone and mineral metabolism. Plasma sodium concentrations, immunoreactive growth hormone measurements, and total protein and albumin concentrations were similar for all groups of rats. If hemoconcentration occurred in flight rats, any decrease in protein could be obscured by the loss of plasma volume. Corticosterone levels did not differ between flight and synchronous groups; flight rats had decreased levels of testosterone compared to synchronous controls, but similar concentrations as compared to vivarium rats.

Title of Study

Measurement of Heart Atrial Natriuretic Peptide Concentrations

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
L.C. Keil	NASA-Ames Research Center

Co-Investigator(s)	Institute
Evans, J.	NASA-Ames Research Center
Grindeland, R.	NASA-Ames Research Center
Popova, I.A.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 440; Hardware p. 457

Objectives/Hypothesis

Although fluid-electrolyte balance has not been determined during flight, post-flight hormone measurement and salt water loading experiments indicate that rats also respond to microgravity by readjustment of their fluid-electrolyte requirements. Atrial natriuretic peptide (ANP) secretion is regulated primarily by atrial pressure. The purpose of the experiment was to determine if space flight exposure had an effect on the concentration of ANP.

Approach or Method

Acid extracts of atria were radioimmunoassayed for 1-28 rat atrial natriuretic peptide. Antibodies to ANP were developed in male, New Zealand rabbits after multiple injections of 1-28 ANP. The amount needed to displace 50% of the labeled hormone was 30.5 ± 0.8 pictograms for a typical standard curve. Inter- and intra-assay coefficient of variation was 7.4 and 7.1%, respectively.

Results

Atria from the flight group contained significantly less ANP than the control groups, including the tail-suspended animals. Reduction of atrial ANP may reflect an increase in hormone secretion during flight. Flight animals may have experienced a rise in atrial pressure that provoked an increase in ANP secretion, or the reduced levels may represent some of the changes in hormonal regulation of fluid-electrolyte metabolism that occur during space flight. The tail-suspension model does not seem to be an appropriate model for simulating the effects of microgravity on ANP metabolism.

Title of Study

Morphological and Biochemical Examination of Heart Tissue: I. Ultrastructural Alterations in Rat Hearts After Cosmos 2044 Compared to Cosmos 1887

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
D.E. Philpott	NASA-Ames Research Center

Co-Investigator(s)	Institute
Popova, I.A.	Institute of Biomedical Problems
Kato, K.	NASA-Ames Research Center
Sapp, W.	Tuskegee University
Miquel, J.	Linus Pauling Institute
Stevenson, J.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 440; Hardware p. 457

Objectives/Hypothesis

Previous studies have concluded that when rats undergo a change from the weightless environment of space to Earth gravity, the heart experiences an increase in load compared to weightlessness, manifesting in tissue anoxia and concomitant mitochondrial disorganization. One investigation of this sort flew on Cosmos 1887. This experiment repeats that study.

Approach or Method

The left ventricles of rats were dissected, dehydrated with ascending concentrations of acetone, infiltrated, embedded, sectioned, and stained for observation by an electron microscope. Volume density was determined by point counting using 240 micrographs (8 x 10) at a magnification of 27,500x. Capillary counts, using randomly selected open-grid squares in the microscope were converted to counts per 600 square microns.

Results

The results were comparable to those in Cosmos 1887. Statistical analysis showed a significant reduction in flight mitochondria and an increase in glycogen and edema. It is possible that the edema may be linked to tissue breakdown, with concomitant increase in osmotic pressure and fluid re-entry into the cells. Lipid accumulation was significant in flight animals as well as an increase in dense bodies. The increase in dense bodies is an indication of increased lysosomal activity which is expected in muscle atrophy. There was also an increase in total free lysosomal enzyme activities in the ventricles, indicating the occurrence of active degradation. Although, at present the basic mechanisms of cardiovascular deconditioning and recovery are not well understood, comparison with tail-suspension data suggest that fixation in space is necessary to obtain the complete picture of heart changes during flight.

Title of Study

Morphological and Biochemical Examination of Heart Tissue: II. Cardiac Morphology After Conditions of Microgravity

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
M.A. Goldstein	Baylor College of Medicine

Co-Investigator(s)	Institute
Schroeder, J.P.	Baylor College of Medicine
Edwards, R.J.	Baylor College of Medicine
Popova, I.A.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 440; Hardware p. 457

Objectives/Hypothesis

The objectives of this study were to: 1) compare papillary muscle and ventricular muscle; 2) determine if there is a change in heart cell size in rat hearts exposed to microgravity; and 3) assess concomitant ultrastructural change.

Approach or Method

Cross-sectional areas of heart cell profiles in light microscope sections were measured for papillary and ventricular muscle samples. Electron microscopy was used to correlate general morphological features in the capillaries with features observed in the larger samples taken from the light microscopy. Stereological analysis and optical diffraction techniques were used for quantitative electron microscopy studies.

Results

Endothelial cell surfaces of capillaries with extended projections and elongated marginal folds were observed in papillary muscle from all groups, but were most pronounced in flight animals. Stereological analysis of papillary muscles revealed increased mitochondrial density values for flight and tail-suspended rats, mitochondrial to myofibril ratios showing the same trend. Optical diffraction studies revealed normal A and Z band spacings. In conclusion, cardiac morphology is affected by space flight, and a continuing concern for a compensated adaption of the heart to microgravity is warranted.

Title of Study

Morphological and Biochemical Examination of Heart Tissue: III. Cyclic AMP Receptor Protein Distribution in Heart Muscle of Rats Flown on Cosmos 2044

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
M.I. Mednieks	University of Chicago

Co-Investigator(s)	Institute
Grindeland, R.E.	NASA-Ames Research Center
Popova, I.A.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 440-41; Hardware p. 457

Objectives/Hypothesis

The effect of space travel on the cardiovascular system has been investigated to determine if measurable changes could be noted, and if such changes might influence the health of the individual. The present study was undertaken in order to gain insight into a specific biochemical mechanism which may be associated with cardiac changes that experimental animals undergo as a consequence of travel in space, the mechanism in question being cyclic AMP-receptor reactions in the cell particulate fraction.

Approach or Method

Tissue homogenates in addition to the subcellular fractions were aziado-labeled and analyzed for total cyclic AMP-binding analysis. Photoaffinity labeling of regulatory subunits (RI and RII) of cyclic AMP dependent protein kinase was carried out to measure cyclic AMP binding protein activities. Polyacrylamide gel electrophoresis, in the presence of sodium dodecyl sulfate, was carried out using a conventional size as well as a mini-gel apparatus.

Results

Cyclic AMP binding protein activities were decreased in heart tissue of flight rats. Densitometric analyses showed a significant decrease of RII in the particulate cell fraction extract. The photoaffinity labeling of soluble fraction was unaffected, as previously observed on Cosmos 1887. A negative correlation resulted when incorporation of total counts of aziado-labeling was based on body weights, while no changes were seen when total label was calculated on the basis of adrenal gland weights. Factors which influence body weight changes therefore may alter hormone response, while changes in a relatively minor aspect of cyclic AMP mediated reactions may have a metabolic affect on an organismic level.

Title of Study

Morphological and Biochemical Examination of Heart Tissue: IV. Altered Myosin Expression in Rat Ventricular Muscle

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
D.B. Thomason	University of Tennessee

Co-Investigator(s)	Institute
Booth, F.W.	University of Texas Health Center
Baldwin, K.M.	University of California, Irvine
Popova, I.A.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 440-1; Hardware p. 457

Objectives/Hypothesis

Microgravity is known to produce cardiovascular deconditioning, changes which may result in part from a regulation of cardiac muscle gene expression at the level of translation. However, little is known about the possible role of transcriptional regulation in the control of the heart during space flight. The purpose of the study was to examine the potential role of transcriptional regulation of myosin expression experienced by rats flown in space.

Approach or Method

Total RNA was extracted from the frozen, powdered muscle with the guanidinium isothiocyanate-cesium chloride method. Varying amounts of total RNA from each sample were electrophoresed on an RNA denaturing gel, probed with a ^{32}P-labeled oligonucleotide probe specific for the beta-myosin heavy chain mRNA, and exposed to x-ray film which was subsequently scanned densitometrically. Statistical differences between the flight and control groups were determined by analysis of covariance for the heavy-chain mRNA expression and mapping of composite densitometric scans.

Results

No differences between the flight and control groups were observed in the myosin protein isoform profile of the cardiac muscle samples. Beta-myosin heavy-chain mRNA expression was also not statistically different. In part, this lack of difference may be artifactual, because on a relative basis, many other species of contractile protein and RNA may also be changing in content, as demonstrated by the covariance mapping, where there were clearly differences identified by the probe between flight and control hearts. Therefore, the cardiovascular deconditioning that is observed may begin early during exposure as a change in transcriptional regulation of gene expression.

Title of Study

Erythroid Colony Formation In-Vitro and Erythropoietin Determinations

Science Discipline

Cardiovascular/Cardiopulmonary

Investigator	Institute
R.D. Lange	University of Tennessee

Co-Investigator(s)	Institute
Michurina, T.	Institute of Developmental Biology
Vacek, A.	Institute of Developmental Biology
Khrushchev, N.G.	Institute of Biophysics, Czechoslovakia
Gibson, L.A.	University of Tennessee Medical Center
Driscoll, T.B.	Baylor College of Medicine
Ichiki, A.T.	University of Tennessee Medical Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 441; Hardware p. 457

Objectives/Hypothesis

In a continuing investigation of the pathogenesis of "space anemia," three red blood cell studies were performed on five flight rats and compared to controls. The bone marrow cell differentials, clonal bone marrow studies of red blood cell colony formation, and plasma erythropoietin determinations were performed, and compared to previous studies of these three parameters.

Approach or Method

Bone marrow smears were made at the landing site; received slides were stained, and bone marrow cells were counted (500 cell differential counts were performed) and classified. For erythroid clonal studies, tibial bone marrow plugs were cultured in Petri dishes; colonies were scored by the ability of hemoglobin-containing cells to reduce 2,7-diaminofluorene. Frozen plasma (0.2 ml) was used for erythropoietin determinations, utilizing a commercial kit.

Results

While some minor variations were found, there were no essential differences in bone marrow differential counts or erythropoietin levels of flight or tail-suspended animals as compared to controls. In studies of colony formation there was a marked increase in the number of CFU-e colonies in frozen flight bone marrow, while no such increase was noted in the "fresh" cultures prepared in Moscow. As with previous studies, no pattern of erythropoiesis has emerged, and the rat may or may not be a valid model to study the decrease in red blood cell mass that occurs in humans exposed to microgravity.

Title of Study

Effect of Spaceflight on Level and Function of Immune Cells: I. Immunology Studies

Science Discipline

Immunology/Microbiology

Investigator	Institute
G. Sonnenfeld	University of Louisville

Co-Investigator(s)	Institute
Mandel, A.D.	NASA-Ames Research Center
Konstantinova, I.V.	Institute of Biomedical Problems
Berry, W.D.	University of Louisville
Taylor, G.R.	NASA-Johnson Space Center
Fuchs, B.B.	Institute of Human Morphology
Rakhmilevich, A.L.	Institute of Human Morphology
Lesnyak, A.T.	Institute of Biomedical Problems
Rykova, M.P.	Institute of Biomedical Problems
Meshkov, D.O.	Institute of Biomedical Problems
Medvedev, A.E.	Institute of Human Morphology

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 441; Hardware p. 457

Objectives/Hypothesis

The purpose of the immunology studies was to continue the systematic attempt to define the range of immunological parameters affected by space flight. The experiments were designed to allow repetition and expansion of studies from a previous flight (Cosmos 1887), with the addition of an antiorthostatic suspension study for direct comparison with space flight effects.

Approach or Method

The first portion of this experiment involved the ability of cells to respond to colony stimulating factor-granulocyte/monocyte (CSF-GM). For colony stimulating factor assays, $1x10^5$ bone marrow cells were suspended with 10% fetal bovine serum and antibiotics containing 3% agar. The second set of studies involved the expression of cell surface markers (T-cell markers, B-cell markers, natural killer cell markers and interleukin-2 receptors) of both spleen and bone marrow cells. Populations stained with fluorescein-labeled antibodies were analyzed using a flow cytometer. In addition, natural killer cell levels were also examined.

Results

Bone marrow cells from flight and tail suspended (TS) rats had reduced response to CSF-GM, demonstrating that response to a recombinant DNA-derived cytokine affecting both monocyte and granulocyte cell populations in bone marrow was compromised by space flight. Spleen cells from flown rats showed increased percentages of pan leukocyte, helper-T, and suppressor-cytotoxic-T-cells, while TS samples had a different pattern of markers. In bone marrow lymphocytic cell population, the percentage of anti-asialo GM-1 bearing, interleukin-2 receptor bearing, pan-T, and helper-T cells was increased after flight, while TS samples again had a different pattern. This shows that suspension is useful for modeling space flight effects of functional immune responses, but not adequate for modeling space flight effects on cell population distribution. Additionally, specific natural killer cell subpopulations were depressed after space flight, while others were not, indicating lack of a general blunting of natural killer cell responses.

Title of Study

Effect of Spaceflight on Level and Function of Immune Cells: II. Proliferation and Cytokines

Science Discipline

Immunology/Microbiology

Investigator	Institute
A.M. Mastro	Pennsylvania State University

Co-Investigator(s)	Institute
Konstantinova, I.V.	Institute of Biomedical Problems
Fuchs, B.B.	Institute of Human Morphology
Taylor, G.R.	NASA-Johnson Space Center
Rakhmilevich, A.L.	Institute of Human Morphology
Lesnyak, A.T.	Institute of Biomedical Problems
Nash, P.V.	Pennsylvania State University

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 441-2; Hardware p. 457

Objectives/Hypothesis

There is ample evidence from the study of human peripheral blood lymphocytes following space flight that many astronauts have an impairment of mitogen-induced T-cell proliferation. Cosmos 2044 afforded the first opportunity to study space flight effects on the proliferation of T-cells and B-cells from rat lymph nodes. The study was also designed to investigate potential mechanisms involved in any absorbed T-cell deficiency.

Approach or Method

Lymphocytes from the superficial inguinal lymph nodes of space-flown rats were tested for proliferation in response to polyclonal activators. Lymph node cells (LNC) were cultured with T-cell or B-cell mitogens, phorbol ester, and calcium ionophore, or T-cell mitogen and the lymphokines interleukin-1 or interleukin-2 (IL-1,IL-2). Lymphocytes were incubated with concanavalin A (Con A), a T-cell mitogen, and tested for IL-2 production.

Results

The proliferation of rat LNC stimulated with polyclonal T or B mitogens was unaffected by the space flight. The proliferation of rat LNC T-cells from flight rats were more responsive to Con A and IL-2, and Con A and IL-1, than were vivarium controls. However, proliferation of flight rat lymphocytes was not greater than synchronous controls, so the increase does not appear to be associated with space flight. Results indicate there may have been a trend toward heightened responsiveness but this was not confirmed statistically. Both flight and suspended LNC produced more IL-2 on average than did controls.

Title of Study

Morphometric and EM Analyses of Tibial Epiphyseal Plates from Cosmos 2044 Rats

Science Discipline

Musculoskeletal

Investigator	Institute
P.J. Duke	University of Texas Dental Branch

Co-Investigator(s)	Institute
Montufar-Solis, D.	University of Texas Dental Branch
Durnova, G.S.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 442; Hardware p. 457

Objectives/Hypothesis

Previous studies have shown that space flight has significant effects on cartilage differentiation within the growth plate, changes which could lead to the observed decreases in linear bone growth and trabecular bone mass. In this study, growth plates of rats flown aboard Cosmos 2044 were analyzed by the same histomorphometric and electron microscopic methods used for other flights and compared to appropriate controls.

Approach or Method

Epiphyses of right tibias were cut from the shaft just above the tibial crest and then split in half in the sagittal plane. One half was decalcified and split again in the sagittal plane; outer portions were embedded for electron microscopy, and middle portions were embedded for light microscopy. The undecalcified half was also split in the sagittal plane; the inner portion was embedded for differential staining of calcified cartilage and the outer portion was split for immunohistochemistry and microprobe studies. Area, perimeter, and shape factor were determined by computerized planimetry. Height and cell number per zone and plate were determined at the light microscopy level. Collagen fibril size and proteoglycan granules per area were determined from micrographs measured on a digitizing tablet.

Results

Flight rats had an increase in height of the proliferative zone (PZ) that was significantly greater than vivarium controls, and a decrease in the hypertrophic, calcification zone (HZC) that differed significantly from all controls. Cell number in the PZ was significantly greater than synchronous controls, and a decrease in cell number in the HZC was significantly different from vivarium animals. Computerized planimetry studies showed no differences between any of the groups with regard to plate area, perimeter, or shape factor. Electron microscopy studies found no difference in collagen fibril length and width, perhaps due to to alteration of fibrils with age. Similarly, the lack of response in tail-suspended animals was also attributed to age.

Title of Study

Skeletal Muscle Atrophy in Response to 14 Days of Weightlessness

Science Discipline

Musculoskeletal

Investigator	Institute
X.J. Musacchia	University of Louisville

Co-Investigator(s)	Institute
Steffen, J.M.	University of Louisville
Fell, R.D.	University of Louisville
Oganov, V.S.	Institute of Biomedical Problems
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 442; Hardware p. 457

Objectives/Hypothesis

Muscles of the rat hindlimb have been used to demonstrate the effects of unloading in weightlessness and in models developed to mimic the response seen during exposure to microgravity. The principal objectives of this study were to ascertain how the vastus medialis (VM) responded to fourteen days of microgravity and if hindlimb unloading (tail-suspension) was comparable to microgravity.

Approach or Method

Three experimental approaches were used: a histochemical evaluation of microscopic morphology, including fibers and capillaries; an assessment of biochemical composition, including protein, DNA and RNA concentrations; and an estimation of metabolic capacity. From each muscle a piece was taken from the belly for histochemical analysis. Cross sections were stained for myosin ATPase under different pH conditions and used for distinguishing fiber types and capillaries. Fiber cross sectional area and cell density measurements were made and capillary density was assessed using an image analysis system. A second portion was utilized for protein, RNA and DNA determinations; both contents and concentrations were determined. Lactate dehydrogenase and citrate synthase activities were measured on lyophilized samples.

Results

Flight animals displayed losses in fiber area and increases in fiber density. Data show that the type II fibers, in both the mixed and unmixed portions of the VM, were affected by the space flight, particularly in those reduced cross-sectional areas in type I fibers of the mixed portion, which averaged between 20-30%. There was a similar atrophy in flight and tail-suspended slow twitch fibers of the mixed VM portion, suggesting a good correlation between ground and flight protocols. The view that significant changes can occur even in the predominately type II muscles was evidenced by increased fiber densities in flight animals. These results suggest that even non-load bearing muscles, such as the VM, show measurable responses to weightless flight. Metabolic studies indicated small reductions in this fast twitch muscle, with a tendency for increased anaerobic capacity (flight and hindlimb unloading).

Title of Study

Effect of Zero Gravity on Myosin Isoform Expression in Rodent Skeletal Muscle

Science Discipline

Musculoskeletal

Investigator	Institute
K.M. Baldwin	University of California, Irvine

Co-Investigator(s)	Institute
Herrick, R.E.	University of California, Irvine
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Oganov, V.S.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 443; Hardware p. 457

Objectives/Hypothesis

The purpose of the present study was to extend previous findings on the effects of space flight on the biochemical properties of rodent fast-twitch and slow-twitch knee extensor muscles. A primary focus was to ascertain the effect on whole homogenate protein, myofibril protein yields, myofibril ATPase, isomyosin distribution patterns, and alpha-glycerolphosphate dehydrogenase activity in vastus intermedius (VI), vastus lateralis (VL), and vastus medialis (VM) muscles.

Approach or Method

Aliquots of homogenized muscles were processed for total protein analysis. Myofibril ATPase specific activity was determined as a free calcium concentration by use of a buffer, expressed as nanomoles of inorganic phosphate released per milligram of myofibril protein per minute. Gel bands of the native myosins separated by pyrophosphate electrophoresis were analyzed densitometrically by directly scanning at 630 nm using a Zenith Soft Laser Densitometer. Isomyosins were fully characterized in terms of their heavy-chain and light-chain composition.

Results

Surprisingly, the muscle mass of the VI did not undergo atrophy in either the flight or tail-suspended groups; however, there was evidence that myofibril yields in the VI were reduced in these same animals. This suggests that degradation of the myofibril machinery in slow-twitch muscle is an early event in the adaptation to zero gravity. Other parameters were not altered in any of the muscles, with the exception that suspension did induce isomyosin shifts in the VI. With regard to the VI, these findings are not fully consistent with Cosmos 1887 observations, suggesting, in part, that there may have been some difficulty in removing the VI from the quadriceps complex.

Title of Study

Bone Biochemistry and Mineral Distribution in the Femurs of Rats after Two Weeks in Space: Circulating Parathyroid Hormone, Calcitonin, and Osteocalcin

Science Discipline

Musculoskeletal

Investigator	Institute
S.B. Arnaud	NASA-Ames Research Center

Co-Investigator(s)	Institute
Fung, P.	NASA-Ames Research Center
Popova, I.A.	Institute of Biomedical Problems
Morey-Holton, E.	NASA-Ames Research Center
Grindeland, R.E.	NASA-Ames Research Center
Yamauchi, M.	University of North Carolina, Chapel Hill
Buckendahl, P.	University of California, Santa Cruz
Bromage, T.	City University of New York

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 442-3; Hardware p. 457

Objectives/Hypothesis

The functional state of the parathyroid gland and the calcitonin cells of the thyroid is critical to the alterations in calcium and bone metabolism during space flight because of the major role each hormone has in their regulation. The purpose of this experiment was to document the early postflight levels of two calcium regulating hormones. Postflight evidence for impaired calcium homeostasis from exposure to space flight as well as the status of these hormones was reported.

Approach or Method

Blood was collected through a heparinized funnel after decapitation and the plasma separated. Parathyroid hormone (PTH) and calcitonin (CT) were measured by radioimmunoassay kits, modified for samples of 50 µl, and compared to appropriate controls. The parathyroid hormone assay uses an antibody raised to an N-terminal fragment of human hormone and human standard. The calcitonin assay used an antibody raised to synthetic human hormone, human standards and tracer. Analysis techniques included student's t-test, analysis of variance, and regression analysis computer programs.

Results

Measurable differences in opposite directions for apparently unrelated reasons were found in plasma concentrations of both PTH and CT. Slight increases in flight PTH, compared to synchronous animals, were indicative of mild hyperparathyroidism, most likely related to impaired kidney function, supported by increases in serum magnesium, phosphorous, creatinine. Plasma CT, on the other hand, in fourteen-week-old rats, failed to show the normal increase with age after two weeks of tail suspension, similar to the postflight result. Postflight circulating levels of PTH appear to reflect disturbances in calcium homeostasis from impaired renal function and of CT in growth connected with the flight. Bone biochemistry revealed mineral deficits and changes in osteocalcin and reducible cross-links in the distal femoral diaphysis. Of interest were similar changes in cross links but not mineral composition in five controls.

Title of Study

Gravity and Skeletal Growth: I. Gravity and Skeletal Growth

Science Discipline

Musculoskeletal

Investigator	Institute
E.R. Morey-Holton	NASA-Ames Research Center

Co-Investigator(s)	Institute
Durnova, G.	Institute of Biomedical Problems
Kaplansky, A.S.	Institute of Biomedical Problems
Doty, S.B.	Columbia University
Partridge, N.C.	St. Louis University School of Medicine
Garetto, L.P.	Indiana School of Dentistry
Roberts, W.E.	Indiana School of Dentistry
Hargens, A.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 443; Hardware p. 457

Objectives/Hypothesis

Experiments flown on Cosmos 1887 were complicated by unexpected postflight processing delays. To differentiate between flight response with minimal recovery time and flight response with extended recovery superimposed, this experiment was repeated with the addition of a tail-suspended model as a control group. Data from this study are difficult to compare with that from Cosmos 1887 due to a 25-day age difference; the larger bones of these animals agree with the older age of the rats.

Approach or Method

Bone area and perimeter were measured at the tibiofibular junction of space-flown and ground control rats. Bone vascularity and bone cells within the tibial diaphysis, and collagen fibrils in the tendons of the foot were studied at the light and electron microscope level. The portion of the tibial shaft immediately proximal to the tibiofibular junction was sawed into 50 µm cross-sections, mounted on slides, and exposed to incident and polarized light.

Results

Visual observations of tibial cross-sections under brightfield or polarized light did not show any obvious differences. Likewise, area and periosteal perimeter measurements showed no significant differences. The lack of any increase in bone mass during the flight period indicates that animals were adults; thus bone mass was not accumulating rapidly during the flight period. Larger, adult rats may require a longer flight period to demonstrate bone changes, particularly in cortical bone since the skeleton is turning over more slowly.

Title of Study

Gravity and Skeletal Growth: II. Morphological Studies of Bone and Tendon

Science Discipline

Musculoskeletal

Investigator	Institute
S.B. Doty	Columbia University

Co-Investigator(s)	Institute
Durnova, G.	Institute of Biomedical Problems
Kaplansky, A.S.	Institute of Biomedical Problems
Holton, E.R.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 443; Hardware p. 457

Objectives/Hypothesis

Previously described results from Cosmos 1887 noted that drastic changes occurred in the vascular system within the diaphyseal bone, evidently in response to the microgravity experience. In addition to the study of the vascular supply to the periosteal region and the determination of osteoblast activity, this study also investigated the structural integrity of the rat foot. This tissue is sensitive to changes in mechanical stress, and it was thought that the reduced activity imposed by space flight might also cause structural changes in these tendons.

Approach or Method

Electron and light microscopy, histochemistry, and morphometric techniques were combined in this study to determine the effects of microgravity on bone cells and the vasculature within the diaphysis of the rat tibia. Silver staining of 3-5 µm sections was carried out to visualize collagen fibers. Osteoblasts were stained for acid phosphate activity to outline the Golgi complex. Cytoplasmic RNA was stained with pyronine so the Golgi complex free of RNA could be visualized by negative contrast. Measurements were made at 320x so that the Golgi presence could be easily determined.

Results

Vasculature changes at the periosteal and sub-periosteal region were not apparent. Electron microscopy showed that vascular inclusions were present in flight rats; however, the blood vessels themselves appeared undamaged. Electron microscopy of the tendons of the foot showed some collagen fibril disorganization but this was not noticeable by light microscopy. Investigations of osteoblasts lining the endosteal surface indicated a reduction in activity, but morphometric measurements suggested that these alterations were not significantly different from controls. The general absence of vascular changes in this study is interesting since this flight was similar in many respects to Cosmos 1887, one notable difference being the almost 55-hour delay before recovery of 1887. This raises the possibility that vascular changes could have occurred when the animals became weight-bearing following re-entry. Following a non-weight bearing period, the resumption of full weight bearing may be detrimental to the vascular system, especially at the periosteal surface of the bone.

Title of Study
Gravity and Skeletal Growth: III. Recovery of Osteogenic Potential

Science Discipline
Musculoskeletal

Investigator	Institute
L.P. Garetto	Indiana University School of Medicine

Co-Investigator(s)	Institute
Morey-Holton, E.R.	NASA-Ames Research Center
Roberts, W.E.	Indiana University School of Dentistry
Durnova, G.N.	Institute of Biomedical Problems
Kaplansky, A.S.	Institute of Biomedical Problems

Research Subject(s)
Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls
5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware
Cosmos 2044 Russian Hardware Suite

More Information
Mission p. 162-8; Publications p. 443; Hardware p. 457

Objectives/Hypothesis
Data from previous space flight missions suggest an initial inhibition of osteoblast histogenesis followed by a postflight recovery response. This study of rat maxillary molar periodontal ligament (PDL) allowed further investigation of the osteoblast histogenesis recovery pattern.

Approach or Method
Samples were demineralized, embedded in plastic, sectioned (4 µm) in the mid-sagittal plane of the medial root of the first molar, and stained with hematoxylin and eosin. An ocular micrometer was used to measure the major and minor nuclear dimensions of 100 cells in each PDL under oil immersion at 1,000x. Nuclear volume for each cell sampled was calculated according to the formula for a prolate spheroid. The fractional distribution of each cell type was expressed as group mean ± SEM. PDL width was also measured at three levels within the mid-root region of the medial root of the first molar.

Results
A comparison of PDL cell populations from the control groups showed no significant differences. Similarly, no differences were seen in any of the nuclear volumes or observed in the width of the PDL. Compared to previous space flight experiments, the data are consistent with a postflight response to replenish pre-osteoblast and restore osteogenic potential. The lack of difference at the sampling time of this study coincides with a crossover point (a point where cell kinetic compartment size passes through the normal range on its way from a suppressed value to a supercompensated level) in the recovery response process.

Title of Study

Gravity and Skeletal Growth: IV. Immunohistochemistry in Calvaria of Rats Flown on Cosmos 2044

Science Discipline

Musculoskeletal

Investigator	Institute
N.C. Partridge	St. Louis University School of Medicine

Co-Investigator(s)	Institute
Morey-Holton, E.R.	NASA-Ames Research Center
Gershan, L.A.	Medical College of Wisconsin
Jeffrey, J.J.	Albany Medical College
Quinn, C.O.	St. Louis University School of Medicine
Lorenz, T.C.	St. Louis University School of Medicine
Durnova, G.N.	Institute of Biomedical Problems
Kaplansky, A.S.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 444; Hardware p. 457

Objectives/Hypothesis

This study was undertaken to investigate whether space flight would change the amount of collagenase detectable in the calvaria of adult rats. It was postulated that the change in blood flow and load bearing connected with weightlessness would change the amount and distribution of collagenase in calvaria. Thus immunohistochemical staining for collagenase was performed on sections of each calvaria as well as a morphological assessment.

Approach or Method

Sections (10 µm) were cut from frozen calvarial tissue blocks taken from an area near the suture lines and including some parietal bone. The amount and distribution of the metalloproteinase, collagenase, was detected in frozen sections by an immunohistochemical technique; the primary antiserum used was a monospecific polyclonal rabbit anti-rat uterine collagenase. Cellular architecture was assessed by counterstaining with hematoxylin and morphological examination.

Results

No difference was observed in the quantity or distribution of collagenase, which was seen to be associated with cells lining the marrow spaces, osteocytic canaliculi, and deposited in the matrix. Morphologically, there appeared to be differences in the calvaria of both the flight and tail-suspended animals. In flight samples, the matrix seemed wider than controls, while in the tail-suspended samples, the marrow space appeared enlarged. It is possible that a shift in blood and a change in loading affects the morphology of the calvaria.

Title of Study

Mineral Distribution and Balance in Rats During Spaceflight

Science Discipline

Musculoskeletal

Investigator	Institute
C. Cann	University of California, San Francisco

Co-Investigator(s)	Institute
Serova, L.V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Rats; Pooled Flight Sample — Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended; Pooled Control Samples; Cosmos 1887 Pooled Basal Control Samples

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 444; Hardware p. 457

Objectives/Hypothesis

Previous studies of mineral distribution and homeostasis have shown significant effects of space flight on the mineral composition of bones and the handling of major trace minerals by the intestine. Data from Cosmos 1129 and 1887 have shown a significant increase in fecal ash, predominantly due to progressive increases of excreted sodium and potassium, and to a lessor extent calcium. Analyses of vertebrae from Cosmos 1887 further suggested that flight bones were more highly mineralized, consistent with other space flight studies. This experiment was primarily to add supplementary and supporting data to these findings, especially for the excreta analyses where measurements were made from pooled samples.

Approach or Method

Fifth lumber vertebrae were split into two segments; separate segments were lyophilized and weighed, and then analyzed as separate samples. In contrast to samples from Cosmos 1887, only isolated vertebral bodies were received; therefore, regional analysis of the vertebral bodies vs. the posterior elements could not be done. Samples of pooled excreta from flight and control groups, each representing half of the total pool for that group, were cleaned, mixed well, and dried. Two random samples (~5 g each) were taken for analysis. Aliquots were weighed, dried, and reweighed to determine wet/dry weight ratio for the sample. Ashing occurred at 500°C for 48 hours, and the residue was weighed and dissolved in ultra pure nitric acid for element analysis. Calcium, magnesium, zinc, manganese and copper were analyzed by atomic absorption spectrophotometry, and phosphorus by ammonium molybdate procedure. Analyses were done in duplicate and results were averaged. Samples from Comos 1887 basal group were included as control for comparisons between flights.

Results

Bones from flight animals were somewhat smaller than those of synchronous, and significantly smaller than those of vivarium animals, due to variance among synchronous rats. Some of this variance may have resulted from an inconsistent separation of posterior elements from the vertebral bodies, due to the fact that the whole vertebral body was not received. This variance also seemed to have prevented significant results in calcium and osteocalcin concentrations between rat bones. Among fecal samples, there were some inconsistent differences in trace element concentrations, probably attributable to dietary differences among groups. No major differences were found between flight and control groups, although calcium, phosphorus and magnesium were lower in the basal group. Dietary differences complicated comparisons with Cosmos 1887 results. However, total excreted mass was higher in flight animals, suggesting that the intestine is much less efficient in metabolizing the organic components of the diet, even while maintaining reasonable efficiency for the mineral components.

Title of Study

Messenger RNA Levels in Skeletal and Smooth Muscles: I. mRNA Decrease in Skeletal Muscle During Spaceflight

Science Discipline

Musculoskeletal

Investigator	Institute
F.W. Booth	University of Texas Medical School

Co-Investigator(s)	Institute
Thomason, D.B.	University of Texas Medical School
Morrison, P.R.	University of Texas Medical School
Oganov, V.S.	Institute of Biomedical Problems
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Smirnov, K.V.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 443-4; Hardware p. 457

Objectives/Hypothesis

The sequence of chemical steps linking non-weightbearing to the loss of muscle protein remains unknown. Using a model of non-weightbearing (tail-suspension) to mimic the effect of microgravity on skeletal muscle, decreases in the mRNAs for skeletal alpha-actin and cytochrome-C have been observed in skeletal muscle. The purpose of this study was to determine if similar events occur in skeletal muscle of rats during space flight.

Approach or Method

RNA was extracted from skeletal muscle by the LiCl-urea method. Hybridizations were performed with a ^{32}P-labelled rat skeletal alpha actin probe consisting of 560 bases of the coding region and with a ^{32}P-labelled 960-base fragment of the rat somatic cytochrome-C gene. The concentration of the mRNA was determined by RNA dot blots. Following autoradiography, laser beam densitometry and scintillation counting were done to estimate ^{32}P bound to the mRNA. Analysis of covariance was used to determine significance among the slopes for intensity and for counts per RNA quantity.

Results

Directional changes in skeletal alpha-actin mRNA in skeletal muscle during space flight were in the same pattern as those previously reported in the non-weightbearing model at 1 g. Decreases of 25% and 36% were found in the vastus intermedius and lateral gastrocnemius muscles, respectively. Cytochrome-C mRNA decreased 36% in the vastus intermedius muscle. No decrease in cytochrome-C mRNA was found in the lateral gastrocnemius muscle in flight and one of the two tail-suspension studies or in the vastus intermediate during tail suspension studies. Thus, as opposed to responses of skeletal alpha-actin mRNA to non-weightbearing, cytochrome-c mRNA changes were not directionally consistent.

Title of Study

Messenger RNA Levels in Skeletal and Smooth Muscles: II. mRNA Levels in Smooth Muscle

Science Discipline

Musculoskeletal

Investigator	Institute
N.W. Weisbrodt	University of Texas Medical Center

Co-Investigator(s)	Institute
Booth, F.W.	University of Texas Medical Center
Lai, M.	University of Texas Medical Center
Thomason, D.B.	University of Texas Medical Center
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Smirnov, K.V.	Institute of Biomedical Problems
Oganov, V.S.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 444; Hardware p. 457

Objectives/Hypothesis

Space flight effects on the structure and function of the gastrointestinal tract have received little study. Although previous investigations suggest that the net function of the gut is unaltered by gravitation changes, more detailed studies are warranted. Data from a newly developed intestinal bypass model suggest that if there are any changes in the gut associated with space flight, they may be expressed as early changes in gene expression in the intestinal smooth muscle. The purpose of this experiment was to define the effects of space flight on the weight and protein content, and on the abundance of actin mRNA in the intestinal smooth muscle of rats flown on Cosmos 2044.

Approach or Method

Intestinal smooth muscle samples were analyzed for changes in weight, protein content, RNA and mRNA levels for actin. Segments of mid-small intestine were removed, opened lengthwise, rinsed, and frozen. After storage at -80 °C, muscles were thawed at 4 °C and lengths measured. The longitudinal layer of smooth muscle was removed, weighted, and processed. For analysis of mRNA actin, a special riboprobe was developed, containing a cDNA insert that codes for a portion of the 3' untranslated region, all of the coding region, and a portion of the 5' untranslated region of the mRNA that in turn codes for the synthesis of smooth muscle actin. While the method used to isolate total RNA yields a relatively pure product, recovery is incomplete and variable. For this reason, the amount of RNA recovered spectrophotometrically was determined and presented as a comparative estimate of the total RNA contained in each segment of longitudinal muscle. Wet weight, total protein, and total RNA were normalized to the length of each segment.

Results

Wet weight, and protein content were less in tissue taken from the flight animals compared to vivarium controls. However, no differences were detected between tissues taken from flight, synchronous, and tail-suspended animals. Detected differences may be explained on the basis of food consumption or weight gain. Total RNA differed among tissues from all groups, with decreasing amounts identified among vivarium, tail-suspended, synchronous and flight groups, respectively. Size fraction of the RNA demonstrated significant degradation. Analysis of northern blots failed to show any hybridization to the riboprobe for smooth muscle actin, more than likely due to the degradation. Although not conclusive, the RNA data suggests that there may be an influence of space flight on intestinal smooth muscle gene expression. That the lowest RNA levels were found in flight animals may indicate the influence of diet and/or space flight; however, since hormonal and other changes also occur during flight, the effect, if any, could be secondary.

Title of Study

Effects of Microgravity in the Adductor Longus Muscle of Rats: I. A Study Employing Neural Cell Adhesion Molecules (N-CAM) Immunocytochemistry and Morphology

Science Discipline

Musculoskeletal

Investigator	Institute
N.G. Daunton	NASA-Ames Research Center

Co-Investigator(s)	Institute
D'Amelio, F.	San Jose State University Foundation
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Harris, E.	San Jose State University
Russell, A.	NASA-Ames Research Center
Binnard, R.	San Jose State University Foundation

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 444; Hardware p. 457

Objectives/Hypothesis

Although the effects of microgravity upon muscle tissue are far from being understood, previous studies have shown that "slow" muscle, mostly composed of type I fibers (e.g. soleus, adductor longus), carry the burden of the changes. This study places emphasis on some particular responses to weightlessness observed in the adductor longus muscle of rats, namely: 1) muscle fiber injury; 2) regenerative phenomena and 3) alterations of the neuromuscular junctions.

Approach or Method

The motor endplate region was identified by acethylcholinesterase activity under the stereomicroscope and dissected; silver-gold ultrathin sections were stained with uranyl acetate-lead citrate, mounted in copper grids (100 mesh), and observed with an electron microscope. For light microscopy observations, fixed adductor samples were stained with hematoxylin and eosin. For N-CAM immunocytochemistry, sections (25 µm) were mounted, rinsed, and incubated with anti-N-CAM rabbit antibodies.

Results

N-CAM immunoreactivity was seen on the myofiber surface, satellite cells, and in regenerating myofibers reminiscent of myotubes. Light microscopy revealed myofiber atrophy, contraction bands and segmental necrosis accompanied by cellular infiltrates of macrophages, leukocytes, and mononuclear cells. The principal electron microscopic changes of the neuromuscular junctions consisted of a decrease or absence of synaptic vesicles, degeneration of axon terminals, increased numbers of microtubules, vacant axonal spaces, and axonal sprouting. These results indicate that major alterations such as myofibrillar disruption and necrosis, muscle regeneration and denervation and synaptic remodeling at the level of the neuromuscular junction may take place during space flight.

Title of Study

Effects of Microgravity in the Adductor Longus Muscle of Rats: II. Quantitative Autoradiographic Analysis of GABA (Benzodiazepine) and Muscarinic (Cholinergic) Receptors in the Forebrain of Rats

Science Discipline

Neuroscience

Investigator	Institute
L.-C. Wu	NASA-Ames Research Center

Co-Investigator(s)	Institute
Daunton, N.G.	NASA Ames Research Center
Krasnov, I.B.	Institute of Biomedical Problems
D'Amelio, F.	San Jose State University Foundation
Hyde, T.M.	National Institute of Mental Health
Sigworth, S.K.	National Institute of Mental Health

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 444; Hardware p. 457

Objectives/Hypothesis

Quantitative autoradiographic analysis of receptors for GABA (gamma-amino-butyric acid) and acetylcholine in the forebrain of space-flown rats was undertaken as part of a joint U.S./U.S.S.R. study to determine the effects of microgravity on the central nervous system, and in particular on the sensory and motor portions of the forebrain. Changes in the binding of these receptors in tissue would provide evidence for possible changes in neural processing as a result of microgravity exposure.

Approach or Method

Tritium-labeled diazepam and quinuclidinyl-benzilate (QNB) were used to visualize GABA (benzodiazepine) and muscarinic (cholinergic) receptors, respectively. The density of tritium-labeled radioligands bound to various regions of the forebrain were measured from autoradiograms. A video camera-based image analysis system was used to quantify densities of the autoradiograms. Within each brain, two different regions (superficial vs. deep or dorsal vs. ventral) were analyzed separately and, because of blocking variations in individual brains, together to determine differences among conditions.

Results

The absence of significant differences in GABA receptor binding between flight and control animals is not in itself conclusive due to the small number and anatomical variations among samples. The most significant finding in this study is the decrease in muscarinic cholinergic receptors in the stratum of flight rats, a down-regulation which conceivably might be a compensatory response to increased release of acetylcholine, or a possible result of decreased dopaminergic transmission stemming from a microgravity-induced reduction in spontaneous motor behavior. Future studies should perhaps address the importance of in-depth observations of the behavior of rats in space regarding motor activities to correlate with the changes in receptor binding sites.

Title of Study

Rodent Tissue Repair: I. Skin Repair Studies

Science Discipline

Musculoskeletal

Investigator	Institute
A.C. Vailas	University of Wisconsin

Co-Investigator(s)	Institute
Durnova, G.	Institute of Biomedical Problems
Kaplansky, A.	Institute of Biomedical Problems
Vanderby, R.	University of Wisconsin
Graf, B.	University of Wisconsin
Sears, J.	University of Iowa
Ashman, R.	University of Texas
Grindeland, R.E.	NASA-Ames Research Center
Martinez, D.	University of Wisconsin
Thielke, R.	University of Wisconsin
Ulm, M.	University of Wisconsin
Griffith, P.	University of Wisconsin

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight, 5 Flight Injured — Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 445; Hardware p. 457

Objectives/Hypothesis

The aim of this experiment was to determine the effects of microgravity on the healing and repair of skin connective tissue and skeletal muscle. Two days preflight, skin and lateral head of the medial gastrocnemius, medial soleus, and fibula of hindlimbs from five of the flight rats were cut and wounds sutured after surgery.

Approach or Method

Flight samples were compared histologically and immunocytochemically to similarly treated tail-suspended, synchronous, and vivarium control animals. All protein markers were isolated from rat sources and antibodies prepared and tested for cross reactivity with other molecules. Non-lesion skin was prepared for measurements of DNA content, collagen content by hydroxyproline, and uronic acid content by an estimation of ground substance.

Results

Skin repair studies were somewhat problematic for the following reasons: 1) it was very difficult to locate the wound and many of the lesions were not the same dimensions and 2) thawing and fixation of frozen tissue caused problems with immunocytochemical staining for better resolution with light microscopy image processing. Significant qualitative differences were not detected for the wound markers collagen type III, hematotoxyline and eosin, and macrophage factor XIII. Other results indicated there was a nonsignificant increase (10%) in flight animal skin DNA concentration; however, data expressed as a ratio of DNA/collagen estimates of the cell or nuclear density that supports a given quantity of collagen showed a dramatic increase in the flight group (33%). This means flight conditions may have slowed down collagen secretion and/or increased cell proliferation in adult rat skin.

Title of Study

Rodent Tissue Repair: II. Changes in Muscle Serine Proteases, Serpins, and Matrix Molecules

Science Discipline

Musculoskeletal

Investigator	Institute
B.W. Festoff	University of Kansas Medical Center

Co-Investigator(s)	Institute
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Rayford, R.A.	Veterans Affairs Medical Center
Reddy, B.R.	Veterans Affairs Medical Center
Rao, J.S.	Veterans Affairs Medical Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

2 Flight Injured Male

Ground-Based Controls

2 Basal, 2 Vivarium, 2 Synchronous, 2 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 444; Hardware p. 457

Objectives/Hypothesis

In microgravity, type I muscle fibers atrophy and lose predominance, especially in slow-twitch muscles. No increase in mononuclear cells has been observed, as is the case with simple denervation, where both types I and II fibers atrophy, without infiltration of cells but with clear satellite cell proliferation. However, degradation of the extracellular matrix (ECM) takes place after denervation and, if reinnervation is encouraged, functional recovery to near control levels may be achieved. No information is available concerning the ECM milieu, the activation of serine proteases, their efficacy in degrading ECM, and the production of locally derived natural protease inhibitors (serpins) in effecting surface proteolytic control. This study was to examine the activation of these enzymes in microgravity and their response to muscle injury, both in space and on the ground.

Approach or Method

Gastrocnemius muscle was crushed by clamping down a hemostat for thirty seconds. Rat cells were grown in microcarrier cultures as a source of purified PNI, and affinity chromatography was used to obtain it. To determine if differences in previously injured gastrocnemius muscles could be detected, nitrocellulose or immobilon-bound samples were sequentially probed with antibodies to plasminogen activator (PA) and two serpins (PAI and PAI-1). PA activity was also determined by amidolytic assay; serpin activity by several synthetic chromogenic assays specific for the target protease. Immunologically stained slides were viewed under epifluorescence with a microscope. Protein determination was estimated using staining.

Results

Although PNI increased in the flight group, levels were less than in the tail-suspended group, as compared to vivarium and synchronous controls. An increase in moles of active PAI-1 occurred after muscle crush, and in all cases PAI-1 was increased compared with basal extracts. Enzyme-linked immunosorbent assays for both serpins indicated that crush injury itself increased the amount of active plus complexed serpin, just significantly greater in injured flight muscles. In adult innervated muscle, uPA activity was barely detectable, uPA mRNA expression was second only to the kidney, suggesting that uPA message in kidney is in "ready reserve" awaiting some type of injury for rapid activation. This supports the theory that neutral, extracellular proteases are essential to degrade components of the old basement membrane/ECM in order to allow for a basement membrane to scaffold so that orderly regeneration can take place. Likewise, from the results it may be speculated that some interference with this "ready reserve" of uPA mRNA after injury characterizes zero gravity.

Title of Study

Rodent Tissue Repair: III. Skeletal Muscle

Science Discipline

Musculoskeletal

Investigator	Institute
W.T. Stauber	West Virginia University

Co-Investigator(s)	Institute
Fritz, V.K.	West Virginia University
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Kaplansky, A.S.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight, 5 Flight Injured — Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 445; Hardware p. 457

Objectives/Hypothesis

Myofiber injury-repair was studied in the rat gastrocnemius following a crush injury to the lower leg prior to flight in order to understand if the regenerative responses of muscles are altered by the lack of gravitational forces during space flight. Skeletal muscle atrophy in actual or simulated weightlessness appears to be due to a combination of local and systemic factors—muscle tension and exogenous growth factors. If gravitational forces are necessary for optimal connective tissue organization and muscle repair, then muscle injuries in microgravity might require a special type of rehabilitation to prevent muscle fibrosis and/or movement dysfunction.

Approach or Method

Histochemical and immunohistochemical techniques were used to examine myofiber, vascular and connective tissue for alterations. Muscle tissues were sectioned at -20 °C in a cryostat at a thickness of 4 µm. Macrophages were localized using an alpha-naphthyl acetate asterase kit. Blood vessels and capillaries in the muscle sections were visualized using a histochemical procedure for the localization of dipeptidyl peptidase IV employing fast blue staining. Localizations of proteinases, proteins, and proteoglycans were performed by indirect immunohistochemical techniques using fluorescein-labeled second antibodies.

Results

In general, the repair process was somewhat similar in all muscle samples with regard to the extracellular matrix organization and myofiber regeneration. Small and large myofibers were present within a newly organized extracellular matrix indicative of myogenesis and muscle regeneration. In the tail-suspended animals, a more complete repair was observed with no enlarged area of non-muscle cell of matrix material visible. In contrast, flight muscle samples were less well differentiated with more macrophages and blood vessels in the repair region, but small myofibers and proteoglycans were, nevertheless, in their usual configuration. Myofiber repair did vary in muscles from different groups, but for the most part resulted in functional muscle tissue. However, an increase in the vascularity of the repair site and in the number of macrophages in flight muscle might suggest the development of granulation tissue at the repair site of the flight animals, or that muscle regeneration was slowed down due to a variation in growth factors such as growth hormone and insulin.

Title of Study

Metabolic and Morphologic Properties of Muscle Fibers and Motor Neurons after Spaceflight: I. Muscle Fibers

Science Discipline

Musculoskeletal

Investigator	Institute
V.R. Edgerton	University of California, Los Angeles

Co-Investigator(s)	Institute
Ohira, Y.	University of California, Los Angeles
Roy, R.	University of California, Los Angeles
Jiang, B.	University of California, Los Angeles
Marini, J.F.	Reseau de Recherches Neuromusculaires
Leger, J.J.	Reseau de Recherches Neuromusculaires
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Krasnov, I.B.	Institute of Biomedical Problems
Oganov, V.S.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 445; Hardware p. 457

Objectives/Hypothesis

The present study allowed several issues raised by Cosmos 1887 to be addressed. These include the difference in atrophy suggested by wet muscle and fiber size data (40%), and the adaptability of selected metabolic enzymes to space flight. Also, a question not addressed in previous studies of tail-suspension or space flight is whether myosin ATPase activities of single fibers changes in parallel with the changes in expression of fast myosin.

Approach or Method

Serial sections (10 µm) were cut. Qualitative staining of ATPase was performed at pH 8.7; quantitative staining for myofibrillar ATPase activity at pH 8.6. Triplicate sections were stained at 37°C with ATP in the substrate medium, and two sections were stained without ATP. The difference in optical density between the with and without substrate was used to calculate activity (optical density/min.). Additional serial sections were stained with monoclonal antibody against fast or slow myosin heavy chain. Fibers were identified as having reacted positively for the slow, fast, or both antibodies.

Results

Significant atrophy was found in both dark and light myosin ATPase fibers following space flight and tail suspension. In suspension, dark and light (Type II and Type I) were 40% and 38% smaller than controls, respectively, while flight fibers were 28% and 38% smaller. The distribution of fibers which were positive to a monoclonal antibody for fast myosin heavy chain increased from 9.6% in controls to 24.1% after space flight; however, the percent responding positively to slow myosin antibody did not change. The ATPase activity in light ATPase fibers was less in flight than control muscle. Those fibers that stained intermediately with ATPase had intermediate quantitative ATPase, SDH, and GPD enzyme activities suggesting that these fibers were in a transitional state.

Title of Study

Metabolic and Morphologic Properties of Muscle Fibers and Motor Neurons after Spaceflight: II. Ventral Horn Cell Responses to Spaceflight and Suspension

Science Discipline

Neuroscience

Investigator	Institute
B. Jiang	University of California, Los Angeles

Co-Investigator(s)	Institute
Roy, R.	University of California, Los Angeles
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Krasnov, I.B.	Institute of Biomedical Problems
Oganov, V.S.	Institute of Biomedical Problems
Edgerton, V.R.	University of California, Los Angeles

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 446; Hardware p. 457

Objectives/Hypothesis

Space flight or hindlimb (tail) suspension result in a loss of mass and in alteration of the metabolic and contractile protein profiles of skeletal muscles towards that resembling faster muscles. Given the influence of motorneurons on muscle properties, ventral horn cells of the lumbosacral enlargement of the spinal cord were studied to determine whether similar adaptations were present in these cells.

Approach or Method

Spinal-cords were quick-frozen and the succinate dehydrogenase (SDH) activity and cross-sectional area (CSA) of the soma of ventral horn cells were measured using a computer enlargement processing system. The optical density (OD) for SDH activity was determined after eight minutes of incubation in a reaction medium which gave a steady-state enzymatic reaction. Soma sizes were determined in cells having a visible nucleus.

Results

Although there were no significant differences in mean CSA and SDH activity, the population distributions of both variables shifted significantly. In flight rats, there was a shift toward smaller cells. Compared to control, the population of SDH activities shifted to higher activities in flight samples, while the distribution shifted toward lower activities in suspended animals. When considering the interactive effects within individual cells, there was a higher percentage of small cells having high SDH activities in the flight compared to control or suspended animals. These contrasting effects of space flight and suspension suggest that the changes observed in ventral horn cells were due to factors other than simply the absence of weight support.

Title of Study

Morphohistochemical, Immunocytochemical, and Biochemical Investigation of Microgravity Induced Nerve and Muscle Breakdown: I. Muscle Histology

Science Discipline

Musculoskeletal

Investigator	Institute
D.A. Riley	Medical College of Wisconsin

Co-Investigator(s)	Institute
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Oganov, V.S.	Institute of Biomedical Problems
Ellis, S.	San Jose State University
Haas, A.L.	Medical College of Wisconsin
Hoh, J.F.Y.	University of Sydney, Australia

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight	Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 445-6; Hardware p. 457

Objectives/Hypothesis

Extended exposure of humans to space flight produces a progressive loss of muscle strength. Rats orbited in longer Cosmos missions manifested more severe atrophy and greater tissue necrosis than those on shorter missions, suggesting the degenerative processes were progressive. The purpose of the present study was to examine the hindlimb muscle from flight rats sacrificed as close to landing as possible so that changes induced by space flight and early readaptation to weight bearing could be distinguished from the changes that resulted from the two-day postflight period during Cosmos 1887.

Approach or Method

Rats were sacrificed eight to eleven hours after landing. The adductor longus (AL), extensor digitorum longus (EDL), and plantaris muscles were cut into sections and stained appropriately for light and electron microscopy. Qualitative atrophic changes in muscle fibers, nerves, neuromuscular junctions, microcirculatory vessels, interstitial tissue and the myotendious junctions were assessed. Estimates of interstitial edema for the AL and EDL muscles were made by quantifying the percentage area of the muscle fibers and non-muscle fiber connective tissues within stained 0.5 µm sections using computer programs. Indirect immunofluorescence was utilized to localize antibodies against ubiquitin conjugates, complement IgG, fibrinogen, immune cell types, red blood cells, platelets, and fast and slow myosins.

Results

This data reconfirms that AL muscle fibers atrophy during space flight and tail-suspension. In the flight AL, absolute mitochondrial content decreased, but the relatively greater breakdown of myofibrillar proteins maintained mitochondrial concentration near normal. At the ultrastructural level a 53% decrease in subsarcolemmal mitochondria concentration was detected in the flight AL muscles compared to vivarium animals. The flight muscles exhibited more eccentric, contraction-like lesions than did the suspended AL, and the high, re-entry g-forces appear to explain this difference. Muscle atrophy appears to increase the tendency to form eccentric contraction-like lesions following reloading; this may reflect weakening of the muscle fiber cytoskeleton and extracellular matrix. Microcirculation is also compromised by space flight such that there is increased formation of thrombi in the postcapillary venules and capillaries.

Title of Study

Morphohistochemical, Immunocytochemical, and Biochemical Investigation of Microgravity Induced Nerve and Muscle Breakdown: II. Muscle Biochemistry

Science Discipline

Musculoskeletal

Investigator	Institute
S. Ellis	San Jose State University

Co-Investigator(s)	Institute
Riley, D.A.	San Jose State University
Giometti, C.S.	Argonne National Laboratory
Oganov, V.S.	Institute of Biomedical Problems
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 446; Hardware p. 457

Objectives/Hypothesis

Earlier studies on microgravity effects by means of hindlimb unloading showed marked changes in relative concentrations of several proteins in rat soleus muscles. The Cosmos 2044 mission offered an opportunity to determine if qualitatively similar changes in protein pattern occurred in skeletal muscle after exposure to microgravity.

Approach or Method

Two types of analyses were performed on the muscle samples. The first was a two-dimensional gel electrophoretic resolution of the proteins extracted with 9 M urea from sections of the adductor longus (AL) muscles. The second was an analysis of the plantaris and EDL for three protease activities using synthetic peptide derivatives: lysosomal tripeptidyl aminopeptidase, cytosolic multicatalytic protease, and cytosolic activity for free calpain protease activity.

Results

The electrophoretic analyses of the AL muscle showed a strong similarity in the pattern of specific protein changes in the atrophying flight and tail-suspended muscle, except the degree of change was more intense in the flight muscle. The flight muscle showed a reduction in the light chains 1s and 1sa, and 2s and the appearance of fast muscle chains 1f, 2f and 3f, suggesting that a conversion of fiber types was initiated by hypogravity. The flight EDL showed a 19% increase of tripeptide peptidyl hydrolase activity, whereas the flight plantaris remained unchanged. Results suggest that tail-suspension does not entirely mimic the muscle atrophy induced by microgravity.

Title of Study

Biomechanical, Biochemical, and Morphological Alterations of Muscle and Dense Fibrous Connective Tissues After 14 Days Spaceflight: I. Connective Tissue Studies

Science Discipline

Musculoskeletal

Investigator	Institute
A.C. Vailas	University of Wisconsin

Co-Investigator(s)	Institute
Durnova, G.	Institute of Biomedical Problems
Kaplansky, A.	Institute of Biomedical Problems
Vanderby, R.	University of Wisconsin
Graf, B.	University of Wisconsin
Sears, J.	University of Iowa
Ashman, R.	University of Texas
Grindeland, R.E.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight, 5 Flight Injured — Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 446; Hardware p. 457

Objectives/Hypothesis

The objectives of this experiment were to characterize the structural and material properties of cortical and trabecular bone samples, and to correlate the biochemical properties of these tissues to the type and quality of structural proteins. This study examined tendon and connective tissue components in muscle for alterations following a space flight of a short duration in a skeletally mature rat.

Approach or Method

Connective tissue studies were conducted in the Achilles and patellar tendons and humeri. The parameters examined included humeri stiffness, flexural rigidity, and failure load; cortical lengths, cross-sectional areas, densities, and moments of inertia. It should be noted that a number of unique methods were employed such as: 1) ultrasonics for humerus elastic properties; 2) lysylpyridnoline collagen cross-link analysis in cortical bone and 3) skin biochemical markers using enzyme digestion.

Results

The study demonstrates that the space flight induced no significant changes for all the parameters studied. However, the results regarding skin biochemical properties showed a significant increase in DNA/mg collagen ratio. Specifically, data indicated that space flight induced an increase in the amount of nuclear material that supports a given quantity of collagen (structural protein). In some cases, the tail-suspended group induced changes in tissues (as compared to the controls) which would suggest in some ways that the model does not mimic all aspects of space flight as an effecter of connective tissue.

Title of Study

Biomechanical, Biochemical, and Morphological Alterations of Muscle and Dense Fibrous Connective Tissues: II. Composition of the Invertebral Disk

Science Discipline

Musculoskeletal

Investigator	Institute
A. Pedrini-Mille	University of Iowa

Co-Investigator(s)	Institute
Maynard, J.A	University of Iowa
Durnova, G.N.	Institute of Biomedical Problems
Krasnov, I.B.	Institute of Biomedical Problems
Chung, C.B.	University of Iowa
Pedrini, V.A.	University of Iowa
Fedler-Troester, J.	University of Iowa

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 446-7; Hardware p. 457

Objectives/Hypothesis

The intervertebral disc is formed by three structures: the nucleus pulposus (NP), the annulus fibrosis (AF), and the cartilaginous endplates (EP). This study was designed to determine the effects of weightlessness on the size, water content, and composition of the lumbar annulli intervertebral disc in space-flown rats. Changes in the composition of the AF may render it unable to withstand swelling pressures of the NP and/or the stress and strain associated with movement under load, making the return to normal gravitational fields potentially hazardous.

Approach or Method

Discs for light microscopy were fixed, cut into halves along the anterior-posterior axis, and stained, with one half embedded flat and the other at 90° to obtain both horizontal and sagittal sections of the disc. For electron microscopy each disc was trimmed while immersed in glutaraldehyde so as to divide each disc into anterior, transitional, and posterior components, with the transitional area representing a small segment on the anterior one-half of the AF immediately adjacent the NP. Longitudinal sections were photographed at 20,000 and 60,000x to determine collagen fibril-proteoglycan relationships. For biochemical analysis minced samples were mixed with various aliquots.

Results

Data indicate that resulting from weightlessness: 1) there was significant reduction in annuli weight which was attributed to an actual loss of tissue components and not to water loss; 2) the annular matrix became proportionally more collagenous, but without the abnormal changes in the relative proportions of Type I or II collagen or number of pyridinoline crosslinks; 3) the collagen proteoglycan ratio in flight animals was significantly greater than controls and 4) when annuli were immersed in water or saline solutions for proteoglycans leached out of annuli, suggesting the presence of abnormal or smaller proteoglycans.

Title of Study
Functional Neuromuscular Adaptation to Spaceflight

Science Discipline
Musculoskeletal

Investigator	Institute
V.R. Edgerton	University of California, Los Angeles

Co-Investigator(s)	Institute
Bodine-Fowler, S.	University of California, Los Angeles
Roy, R.	University of California, Los Angeles
Hodgson, J.	University of California, Los Angeles
Kozlovskaya, I.B.	Institute of Biomedical Problems
Sirota, M.G.	Institute of Biomedical Problems
Kiezuetzov, S.L.	First Moscow Medical Institute
Stepantsov, V.V.	Institute of Biomedical Problems

Research Subject(s)
Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls
5 Laboratory

Key Flight Hardware
Cosmos 2044 Russian Hardware Suite

More Information
Mission p. 162-8; Publications p. 446-7; Hardware p. 457

Objectives/Hypothesis
This study was designed to determine the effects of the absence of weight support on flexor and extensor muscles of the hindlimb. These effects were assessed morphologically and biochemically from muscle biopsies taken from a slow extensor: the soleus; a fast extensor: the medial gastrocnemius (MG); and a fast flexor: the tibialis anterior (TA). A second objective was to determine the relative importance of activity (by EMG) and force (by joint torque) on the adaptation of muscle.

Approach or Method
Pre- and postflight EMGs were analyzed using amplitude histograms, scatterplots, and joint probability density distributions of rectified, smoothed EMGs. Of the two flight animals only one provided a complete data set from implanted soleus, MG and TA muscles. Muscle biopsies of 8-14 mg were taken from two independent sites with a Bergstrom needle. For each biopsy mean fiber cross-sectional area and succinic dehydrogenase (SDH) activity were measured. Joint probability distribution was generated on a logarithmic scale using three consecutive trials and totaling 20,000 data points.

Results
Activity of the TA muscles appeared unchanged after the flight, while the amplitude of soleus EMG was reduced, and MG amplitude was elevated, possibly to compensate for the soleus. Two weeks postflight, MG amplitude had declined to normal values but recovery of soleus was incomplete. Joint probability distribution showed a similar correlation between soleus and MG. This redistribution may be caused by a reduction of activity in the vestibulospinal pathways which normally excites motorneurons innervating the slow motor units of extensor muscles. Mean cross-sectional area of MG and soleus fibers were increased postflight, while TA fibers were significantly smaller. Mean SDH activity was not significantly different in soleus, but decreased in postflight biopsies of the MG and TA.

Title of Study

Studies of Vestibular Primary Afferents in Normal, Hyper- and Hypogravity

Science Discipline

Neuroscience

Investigator	Institute
M.J. Correia	University of Texas Medical School

Co-Investigator(s)	Institute
Kozlovskaya, I.B.	Institute of Biomedical Problems
Sirota, M.G.	Institute of Biomedical Problems
Perachio, A.A.	University of Texas Medical School
Dickman, D.J.	University of Mississippi Medical School

Research Subject(s)

Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls

2 Synchronous, 4 Laboratory

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 447; Hardware p. 457

Objectives/Hypothesis

This study was conducted to determine if the task of making numerous coordinated active horizontal eye and head movements during space flight modified the response of vestibular primary afferents to controlled passive rotations. Since a multi-axis rotator could not be placed on the spacecraft, it was assumed that if these afferents could be tested immediately post flight, information could be obtained about the dynamic properties of the horizontal semicircular canals before they recalibrated to the terrestrial gravitational environment.

Approach or Method

Head restraint rings were chronically fixed to animals' heads; corneo-retinal potential electrodes for recording eye movements were chronically secured in small holes drilled in the bone near the outer canthi above and below one eye. Of the five monkeys operated on, two were flown while the remaining three served as ground controls. Single unit recordings were made, using tungsten microelectrodes, from semi-circular canal and otolith primary afferents. During all recording sessions animals were awake; during eye movement tests animals were aroused with auditory cues and tested using step, sinusoidal, and sum of sinusoidal rotations about an Earth vertical axis and axes other than Earth vertical.

Results

The responses from the horizontal canal afferents suggest that the vestibular end-organ remains normal during and following activities related to the flight; however, it appears that the gain and neural adaptation increase. Also, the "DC bias" of horizontal nystagmus during horizontal axis constant velocity rotation was greater for the two flight monkeys when they were tested postflight day one (R+1) as compared to day nine (R+9), and horizontal nystagmus during step rotation about an Earth vertical axis, with horizontal canals in the plane of rotation, produced roughly the same results at R+1 as R+9. But when the head was pitched down 45° on R+1, the nystagmus slow phase velocity was greater and the duration was doubled. This suggests that this otolith-mediated response to changing linear acceleration, and the response involving the interaction of the horizontal and vertical semicircular canals and otoliths, did not completely recalibrate immediately after the flight (R+1).

Title of Study

Adaptation of Optokinetic Nystagmus to Microgravity

Science Discipline

Neuroscience

Investigator	Institute
B. Cohen	Mount Sinai School of Medicine

Co-Investigator(s)	Institute
Kozlovskaya, I.B.	Institute of Biomedical Problems
Raphan, T.	Brooklyn College
Solomon, D.	Mount Sinai School of Medicine
Helwig, D.	Mount Sinai School of Medicine
Cohen, N.	Mount Sinai School of Medicine
Sirota, M.G.	Institute of Biomedical Problems
Yakushin, S.	Institute of Biomedical Problems

Research Subject(s)

Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls

2 Synchronous, 4 Laboratory

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 447; Hardware p. 457

Objectives/Hypothesis

The goal of these experiments was to study the effect of adaptation to microgravity on the various components of the vestibulo-ocular reflex (VOR) of two space-flown rhesus monkeys. Horizontal, vertical, and roll eye movements were recorded in these and six other monkeys implanted with scleral search coils.

Approach or Method

Pre- and postflight experiments were performed on juvenile (3-4 kg) monkeys who had been implanted with head bolts for stabilization and two scleral search coils on one eye. Eye movements were induced by rotating the animals or the visual surround in a three-axis vestibular and optokinetic stimulator. Animals were rotated around a vertical axis to determine the gain of the horizontal, vertical, and roll VOR; they were subjected to off-vertical axis rotation (OVAR) to determine steady state gains and effects of gravity on modulations in eye position and eye velocity. Animals were also tested for cross coupling of horizontal to pitch and roll optokinetic after-nystagmus (OKAN) and for tilt dumping of post-rotatory nystagmus.

Results

The gain of horizontal VOR was close to unity when animals were tested fifteen and eighteen hours after flight. VOR gain values were similar to those registered before the flight. If the gain of the horizontal VOR changes in microgravity, it must revert to normal soon after flight. Steady state velocities of nystagmus induced by OVAR were unchanged by adaptation to microgravity, and the phase of modulations was similar before and after flight. However, modulations in horizontal eye velocity were on average about 50% larger for angles of tilt of the axis of rotation between 50° and 90° after flight. The difference in both animals was similar and significant. One animal lost its ability to tilt-dump its nystagmus. This loss persisted several days after return and implies an alteration in spatial orientation of velocity storage after flight. Results are consistent with the postulate that adaptation to microgravity causes alterations in the way that otolith information is processed in the central nervous system.

Title of Study

Radiation Dosimetry and Spectrometry: Passive Systems

Science Discipline

Radiation/Environmental Health

Investigator	Institute
E.V. Benton	University of San Francisco

Co-Investigator(s)	Institute
Frank, A.L.	University of San Francisco
Benton, E.R.	University of San Francisco
Dudkin, V.E.	Institute of Biomedical Problems
Marennyi, A.M.	Institute of Biomedical Problems

Research Subject(s)

Not Applicable

Ground-Based Controls

Not Applicable

Key Flight Hardware

Radiation Detectors: Cosmos 2044 Radiation Dosimeters; Temperature Recording System-Modification 1 (ATR-4)

More Information

Mission p. 162-8; Publications p. 447-8; Hardware p. 524-5, 534-5, 554-5

Objectives/Hypothesis

This experiment measured radiation under five conditions: 1) depth dose under very thin shielding on the outside of the spacecraft; 2) low energy, heavy particle LET spectra under very low shielding (outside the spacecraft); 3) the neutron spectra inside and outside the spacecraft; 4) high energy (> 1 MeV) neutron fluxes and dose equivalent rates averaged over mission duration and 5) the thermal (£ 0.2 eV) and resonance (0.2 eV < E < 1 MeV) neutron fluxes and dose equivalent rates over mission duration.

Approach or Method

The Cosmos 2044 biosatellite mission offered the opportunity for radiation measurements under conditions which are seldom available (an inclination of 82.3° and altitude of 294 x 216 km). Measurements were made on the outside of the spacecraft under near-zero shielding conditions. Also, this mission was the first in which temperature recorders (ATR-4) were flown to record the temperature profiles of detector stacks. As in previous experiments, plastic nuclear track detectors (PNTDs), thermoluminescent detectors (TLDs), and nuclear emulsion stacks were used. Also neutron monitors of ^{59}Co activation foils, fission foil high energy detectors, and ^{6}LiF low energy detectors were used.

Results

The TLD depth dose results show a greater spread in dose rates as compared with Cosmos 1887, with a greater maximum (minimum shielding) and lesser minimum (maximum shielding). This is explained by the fact that the higher inclination, lower altitude orbit intersected greater electron fluxes at high latitudes in the horns of the electron belt, but lesser trapped proton fluxes in passing beneath the South Atlantic Anomaly. The PNTDs measured a smaller flux of particles with LET >4 keV μm^{-1} on Cosmos 2044, which is consistent with the TLD results. The measured neutron fluxes, outside the spacecraft, were smaller by factors of up to two from previous measurements made inside the Cosmos spacecraft. Total absorbed dose rates varied from 2.5 x 10^5 to 8.3 mrad d^{-1} under shielding of 0.0146 to 3.20 g/cm^{-2} LiF. For particles with LET >4 keV μm^{-1}, dose rates varied from 7.01 mrad d^{-1} (53.8 mrem d^{-1}) to 1.20 mrad d^{-1} (12.3 mrem d^{-1}) under shielding of 0.164 to 1.95 g/cm^{-1} composite materials.

Title of Study

Hepatic Function in Rats After Spaceflight: I. Analyses of Selected Parameters of Carbohydrate, Amino Acid, Lipid, and Xenobiotic Metabolism

Science Discipline

Regulatory Physiology

Investigator	Institute
A.H. Merrill	Emory University School of Medicine

Co-Investigator(s)	Institute
Popova, I.A.	Institute of Biomedical Problems
Wang, E.	Emory University School of Medicine
Mullins, R.E.	Emory University School of Medicine
LaRoque, R.	Emory University School of Medicine
Hargrove, J.L.	Emory University School of Medicine
Morgan, E.T.	Emory University School of Medicine
Bonkovsky, H.L.	Emory University School of Medicine

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 447-8; Hardware p. 457

Objectives/Hypothesis

Since the liver is basically a central "clearing house" for the metabolism of most nutrients, drugs, and other foreign compounds, further studies of the effects of space flight on the organ appeared warranted. Previous findings suggest that the xenobiotic metabolism is altered by space flight. In attempts to further these findings, described in this report are additional data from analyses of liver samples and serum samples from space-flown rats.

Approach or Method

Liver and plasma samples were analyzed, with established methods, for hepatic protein (with bovine serum albumin as standard), glycogen (rabbit liver glycogen standard) and lipids, as well as the activities of a number of key enzymes involved in metabolism of these compounds and xenobiotics. DNA was quantified using calf thymus DNA as standard. Cytochrome P-450 was measured spectrophotometrically, and by the standard assays of testosterone metabolism and immunochemistry. Other enzyme and serum analyses were conducted using an analyzer.

Results

The major differences between the flight group versus the synchronous control were: elevations in microsomal protein, liver glycogen content, tyrosine aminotransferase, and tryptophan oxygenase; and reductions in sphingolipids and the rate-limiting enzyme of heme biosynthesis, delta aminolevulinic acid synthase. These results support the hypothesis that space flight alters liver function; however, results with these samples differed notably from those of Skylab 3 and Cosmos 1887, presumably due to the conditions of space flight and/or the postflight recovery period.

Title of Study

Hepatic Function in Rats After Spaceflight: II. Glycogen Studies

Science Discipline

Regulatory Physiology

Investigator	Institute
S.M. Cormier	University of Louisville

Co-Investigator(s)	Institute
Racine, R.N.	University of Louisville
Popova, I.A.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 448; Hardware p. 457

Objectives/Hypothesis

Research from previous space flights has shown marked differences in hepatic glycogen and lipid levels; however, the findings have been somewhat contradictory in some instances. Since dietary effects were held relatively constant, alterations in lipid or glycogen storage due to space flight may indicate important metabolic alterations in liver function. This study uses morphometric techniques to examine glycogen and lipid levels in flight and ground control animals.

Approach or Method

The caudate lobe of each liver was removed and cut into small pieces. Semi-thin (1.0 µm) plastic sections (Epon), were stained for glycogen; another section from the same sample was stained with and analyzed for lipid. Twenty-five areas were enumerated for each specimen compartment (lipid, glycogen, nucleus, etc.) and the average percent calculated. Analyses were performed with an image analysis system equipped with a monochrometer. Kupffer cells, hepatocyte nuclei, and fluid-filled spaces were measured from stained 5 µm paraffin sections.

Results

Glycogen levels in flight rats were found to be significantly elevated over controls. Lipid was also higher, but not significantly different. Hepatocytes appeared to be larger in flight animals due to area attributed glycogen. Sinusoids were less prominent in flight animals, and flight Kupffer cell population appeared to be reduced per total area, possibly reflecting changes in liver immune function. Alterations in the storage of glycogen and number of Kupffer cells suggests an important effect of space flight that may have important implication for long-term flight.

Title of Study

Rat Testis Morphology and Physiology

Science Discipline

Regulatory Physiology

Investigator	Institute
R.P. Amann	Colorado State University

Co-Investigator(s)	Institute
Serova, L.V.	Institute of Biomedical Problems
Deaver, D.R.	Pennsylvania State University
Zirkin, B.R.	John Hopkins University
Grills, G.S.	Colombia University
Sapp, W.J.	Tuskegee University
Veeramachaneni, D.N.R.	Colorado State University
Clemens, J.W.	Pennsylvania State University
Banerjee, S.D.	John Hopkins University
Gruppi, C.M.	Columbia University
Wolgemuth, D.J.	Columbia University
Williams, C.S.	Tuskegee University

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 448; Hardware p. 457

Objectives/Hypothesis

There is seemingly contradictory evidence on the effects of space flight on testicular function in mammals. The reason for abnormalities of the endocrine and possible exocrine (spermatogenic) functions of the testes are unknown, but could be related to altered function of the hypothalamus or adenhypophysis, altered fluid distribution in the body, and/or restricted blood and lymph flow within the testes. In this study, histology and testicular gene expression were studied to evaluate effects of space flight on testicular function.

Approach or Method

Using light microscopy, testicular tissue was evaluated for normalcy of both seminiferous epithelium and interstitial tissue. In addition, 2 µm sections were stained with toluidine blue for enumeration of nuclei of spermatogonia and Sertoli cells. The number of homogenization resistant spermatids per gram of tissue was determined to measure the efficiency of sperm production. Other operations included Northern-blot analysis for expression of selected genes (hsp70 and hsp90), quantification of testosterone and receptors of luteinizing hormone (LH), and morphometric analysis of Leydig cells by electron microscopy.

Results

Two of five flight and three of five vivarium rats had abnormal testes before launch; their data were excluded. Diameter of seminiferous tubules and numbers of germ cells per tubule cross section were lower in flight rats; however, ratios of germ cells to each other, or to Sertoli cells, and number of homogenization resistant spermatids did not differ from control values. Neither was there an effect on normal expression of testis-specific hsp gene products, or evidence for production of stress-inducible transcripts of hsp70 or hsp90 genes. Concentration of receptors for rLH in testicular tissue, and surface densities of smooth endoplasmic reticulum and peroxisomes in Leydig cells, were similar in flight and controls animals. However, concentrations of testosterone in flight testicular tissue and peripheral blood were significantly decreased, by up to 20%.

Title of Study

Structural Changes and Cell Turnover in the Rat's Small Intestine Induced by Spaceflight.

Science Discipline

Regulatory Physiology

Investigator	Institute
R.W. Phillips	Colorado State University

Co-Investigator(s)	Institute
Smirnov, K.V.	Institute of Biomedical Problems
Moeller, C.L.	Colorado State University
Sawyer, H.R.	Colorado State University

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 448; Hardware p. 457

Objectives/Hypothesis

The purpose of this project was to test the hypothesis that the generalized, whole-body decrease in synthetic activity due to microgravity conditions encountered during space flight would be demonstrable in cells and tissue characterized by a rapid rate of turnover. Jejunal mucosal cells were chosen as a model since these cells are among the most proliferative in the body.

Approach or Method

Sections 1 µm thick were cut from each of the five sample segments from each of the three jejunal regions per animal and stained with toluidine blue. To accurately determine the mitotic index for each respective region, at least 2,000 cells per region per animal were examined. To determine villus length and crypt depth, at least twenty villi and crypts were measured per region per animal using a computerized image analysis system coupled to a bright field microscope equipped with a 4x objective and video camera. All data were statistically analyzed by analysis of variance and differences between means were detected.

Results

The percentage of mitotic cells present on the crypts of Lieberkuhn in the proximal, middle, and distal regions of flight rats did not differ significantly from controls. Although the ability of jejunal cells to divide by mitosis was not impaired in the flight group, there was, however, a reduction in the length of villi and depth of crypts. Since villi in flight rats were lined by normal mucosal cells, the concomitant reduction in villi height and crypt depth probably reflects changes (e.g. shrinkage) in the connective tissue core of villi and is not due to an impairment in the migration of newly proliferated cells needed to replace those desquamated.

Title of Study

Pineal Physiology in Microgravity, Relation to Gonadal Function

Science Discipline

Regulatory Physiology

Investigator	Institute
D. Holley	San Jose State University

Co-Investigator(s)	Institute
Krasnov, I.B.	Institute of Biomedical Problems
Soliman, M.R.I.	Florida A & M University
Asadi, H.	San Jose State University

Research Subject(s)

Rattus norvegicus (Wistar Rat)

4 Flight Male

Ground-Based Controls

2 Vivarium, 5 Synchronous, 4 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 449; Hardware p. 457

Objectives/Hypothesis

Since the pineal is an important link to the environment, it is conceivable that exposure to space flight might alter the function of this gland and, in turn, affect various physiological functions including the circadian timing system and reproduction. Given the link between microgravity exposure and perturbation of calcium metabolism, and that the pineal is apparently one of the only "soft tissues" to calcify, this study examined pineal calcium content, along with serotonin metabolism.

Approach or Method

Serotonin (5-HT) and 5-hydroxyindole acetic acid (5-HIAA), a major metabolite of serotonin, were analyzed in filtered homogenates injected into a reverse phase column of high pressure liquid chromatograph. The melatonin contents were determined by radioimmunoassay using "ultraspecific" melatonin antiserum. Total calcium content was determined by atomic absorption spectrophotometry using an electrothermal atomizer equipped with a carbon rod. Groups were analyzed by one-way analysis of variance and other statistical methods within a 95% confidence limit.

Results

Pineal serotonin and pineal 5-HIAA contents of flight and tail-suspended rats were significantly higher than the synchronous controls, indicating that the space environment did have an effect on pineal 5-HT content and its turnover. This would be consistent with increased melatonin secretion during the space flight which may have been involved in noted antigonadal activity. The adrenal hypertrophy in flight rats as evidenced by a significant increase in relative adrenal weights and plasma corticosterone levels would indicate a chronic stress response. Past studies suggest that the deposition of calcium may be related to polypeptide secretion by the pineal; pineal calcium levels were elevated in flight and tail-suspended rats

Title of Study

The Effect of Spaceflight on Pituitary Oxytocin and Vasopressin Content

Science Discipline

Regulatory Physiology

Investigator	Institute
L.C. Keil	NASA-Ames Research Center

Co-Investigator(s)	Institute
Evans, J.	NASA-Ames Research Center
Grindeland, R.	NASA-Ames Research Center
Krasnov, I.B.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 448; Hardware p. 457

Objectives/Hypothesis

Disturbances in fluid and electrolyte balance have been noted in humans exposed to space flight, as shown by a loss of plasma volume and increased excretion of sodium and potassium. Upon return to Earth these imbalances are quickly corrected with rehydration and increased renin-angiotensin-aldosterone activity. The purpose of these investigations was to measure levels of pituitary oxytocin (OT) and vasopressin (VP) as possible indicators of changes in fluid-electrolyte balance during flight.

Approach or Method

An aliquot of the pituitary homogenate (1 ml of 0.1 N HCL) was diluted 1:200,000 in a 0.05 m phosphate assay buffer for radioimmunoassay of OT and VP. To eliminate interassay variability, flight and control aliquots were measured within the same OT or VP radioimmunoassay. After hormone levels were determined, protein concentrations were measured by assay with bovine serum albumin as the standard. Hormone concentrations were then calculated as a function of total protein for each posterior pituitary homogenate.

Results

The VP content of flight rats was 32%, 32%, and 20% lower than synchronous, vivarium, and tail-suspended animals, respectively, indicating that the animals may have been dehydrated during flight, or, alternatively, pituitary stores of the hormones may have been reduced due to decreased synthetic activities of the magnocellular neurons. However, increased hemotocritis in flight rats also raises the possibility that blood volume was reduced which would also be stimulus for VP secretion. Since it has been pointed out that OT may be released in response to "neurogenic" stress, whereas VP is released in response to "physical" stress, perhaps the observed decrease in pituitary OT may be attributed to a chronic neurogenic stress the rats experienced during flight in their efforts to adapt to microgravity.

Title of Study

Effect of Microgravity on: I. Metabolic Enzymes in Type I, IIA, and IIB Muscle Fibers

Science Discipline

Regulatory Physiology

Investigator	Institute
O.H. Lowry	Washington University School of Medicine, St. Louis

Co-Investigator(s)	Institute
Krasnov, I.B.	Institute of Biomedical Problems
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Nemeth, P.M.	Institute of Biomedical Problems
McDougall, D.B.	Washington University, St. Louis
Choksi, R.	Washington University, St. Louis
Carter, J.G.	Washington University, St. Louis
Chi, M.M.Y.	Washington University, St. Louis
Manchester, J.K.	Washington University, St. Louis
Pusateri, M.E.	Washington University, St. Louis

Research Subject(s)

Rattus norvegicus (Wistar Rat)

2 Flight Male

Ground-Based Controls

2 Vivarium, 2 Synchronous, 2 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 449; Hardware p. 457

Objectives/Hypothesis

Individual fibers of any given muscle vary widely in enzyme composition, a fact obscured when enzyme levels of the whole muscle are measured. Therefore, this study was to assess the effects of microgravity and hind-limb unloading on the enzyme patterns within a slow twitch muscle (soleus) and a fast twitch muscle (tibialis anterior, TA).

Approach or Method

Samples were prepared for assays two different ways. In one method, samples of 0.5 µg were added to 5 µl of special detergent-containing medium known to preserve without loss all but a few of the enzymes of interest. In an alternate method, thinner sections (16 µm) were stained for myosin ATPase to type the individual fibers, while thicker slices (32 µm) were dissected from individual fibers identified as to type by the adjacent stained sections. Altogether, over 2,200 individual enzyme measurements were made.

Results

Average fiber size was much smaller for both flight and tail suspended muscles ($P<0.01$) than the synchronous samples. Pyruvate kinase, glycerol-3-phosphate dehydrogenase, and hexokinase activities were higher in both flight and tail suspended soleus muscles, while 3-ketoacid CoA transferase was decreased. In contrast there were only two statistically significant differences ($P<0.05$) between TA enzyme activities of synchronous fibers and those of either flight or tail suspended TA fibers: Hexokinase activity of one tail suspended sample averaged 57% higher than the average for the higher synchronous fiber set; thiolase activity of one flight sample was 27% lower than the average for the lower synchronous sample.

Title of Study

Effect of Microgravity on: II. Metabolic Enzymes, Neurotransmitter Amino Acids, and Neurotransmitter Associated Enzymes in Selected Regions of the Central Nervous System

Science Discipline

Regulatory Physiology

Investigator	Institute
O.H. Lowry	Washington University School of Medicine, St. Louis

Co-Investigator(s)	Institute
Krasnov, I.B.	Institute of Biomedical Problems
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Nemeth, P.M.	Washington University, St. Louis
McDougall, D.B.	Washington University, St. Louis
Choksi, R.	Washington University, St. Louis
Carter, J.G.	Washington University, St. Louis
Chi, M.M.Y.	Washington University, St. Louis
Manchester, J.K.	Washington University, St. Louis
Pusateri, M.E.	Washington University, St. Louis

Research Subject(s)

Rattus norvegicus (Wistar Rat)

2 Flight Male

Ground-Based Controls

2 Vivarium, 2 Synchronous, 2 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 449; Hardware p. 457

Objectives/Hypothesis

Six key metabolic enzymes plus glutaminase and glutamate decarboxylase (GAD), as well as glutamate, aspartate and GABA (gamma-aminobutyric acid), were measured in eleven regions of the hippocampal formation of synchronous, flight, and tail-suspended rats.

Approach or Method

All of the assays were performed with samples dissected from 20 µm freeze dried coronal microtome sections; the size of utilized sample and preparation for assay varied with the substance to be measured. All of the methods employed were based on the conversion of NAD^+ to NADPH, NADH to NAD^+, or NADPH to $NADP^+$. The amount of pyridine product formed varied from about $1x10^{-12}$ mole in the aspartate assays to about $200x10^{-12}$ mole in the pyruvate kinase assays. It was therefore necessary in all cases to increase the sensitivity 1,000 to 10,000-fold by enzymatic cycling.

Results

Glucose-6-P dehydrogenase and especially aspartate aminotransferase varied least among the different regions. Glutaminase, associated with the role of glutamate as a transmitter, showed a wider range of activities than any of the six purely metabolic enzymes; moreover, the distribution did not resemble any of these. Both glutamate and aspartate varied over about a 30% range among the twelve subdivisions of the hippocampal formation analyzed. GABA data were somewhat more consistent than GAD data, with relatively high levels for both found in the fascia dentate and the pyramidal cell and molecular layers. While major differences were observed in the normal distribution patterns of each enzyme and amino acid, no substantive effects of either microgravity or tail suspension on these patterns were clearly demonstrated.

Title of Study

Growth Hormone Regulation, Synthesis and Secretion in Microgravity: I. Secretion of Growth Hormone

Science Discipline

Regulatory Physiology

Investigator	Institute
R.E. Grindeland	NASA-Ames Research Center

Co-Investigator(s)	Institute
Hymer, W.	Pennsylvania State University
Vale, W.	The Salk Institute, La Jolla
Sawchenko, P.	The Salk Institute, La Jolla
Ilyina-Kakueva, E.I.	Institute of Biomedical Problems
Popova, I.	Institute of Biomedical Problems
Krasnov, I.B.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 449; Hardware p. 457

Objectives/Hypothesis

Changes in the musculoskeletal, immune, vascular, and endocrine system of the rat occur as a result of short-term space flight. Since pituitary growth hormone (GH) plays a role in the control of these systems, and since an earlier space flight (Spacelab-3) showed that GH cell function was compromised in a number of postflight tests, the Spacelab experiment was repeated and extended in two subsequent flights: Cosmos 1887 and Cosmos 2044, the latter including a tail-suspension control model.

Approach or Method

Cells were prepared from individual pituitary glands by trypsinization. Concentrations of immunoreactive GH and PRL in culture media and extracts were determined by established enzyme immunoassays. Immunocytochemistry for GH cells was done using a diaminobenzidine procedure; an optical analysis system was used to quantify the area of GH-specific cytoplasmic staining. Pooled cells were incubated in antisera overnight, counterstained with propidium iodide, and analyzed with a flow cytometer for determinations of cell percentages, intensity of hormone fluorescence, and cytoplasmic granularity.

Results

There was a marked reduction in flight levels of biologically active GH (bGH). The intracellular concentrations of iGH before or after the culture tended to be similar between all groups; however, intracellular concentrations of bGH in the flight and tail-suspended groups were always significantly lower than controls. In general, the levels of iGH in media of the first and second three-day cultures were not significantly different. The results provide further insight to the hypothesis that exposure to microgravity could alter the secretory activity of a subpopulation of GH cells, perhaps mediated through changes in intracellular packaging of the hormone molecule. Data show that GH cells have not recovered their ability to secrete bGH up to two weeks postflight, the longest period studied thus far.

Title of Study

Growth Hormone Regulation, Synthesis and Secretion in Microgravity: II. Hypothalamic GH-Releasing Factor, Somatostatin Immunoreactivity, and mRNA Levels

Science Discipline

Regulatory Physiology

Investigator	Institute
P.E. Sawchenko	The Salk Institute, La Jolla

Co-Investigator(s)	Institute
Vale, W.	The Salk Institute, La Jolla
Arias, C.	The Salk Institute, La Jolla
Krasnov, I.B.	Institute of Biomedical Problems

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 449; Hardware p. 457

Objectives/Hypothesis

Immunohistochemical analysis from a previous investigation (Cosmos 1887) suggested preferential effects on hypophysiotropic principles involved in the regulation of growth hormone secretion and synthesis. To provide an additional, more penetrating analysis, this study attempted to complement immunohistochemical analysis of growth hormone-releasing factor (GRF) and somatostatin (SS) staining with quantitative, *in situ* assessments of messenger RNAs encoding the precursors for both these hormones.

Approach or Method

Longitudinally bisected hypothalami were sectioned 20 µm thick and stained with a conventional avidin-biotin-immunoperoxidase procedure. For GRF, a polyclonal antiserum raised in rabbits against synthetic rat GRF[1-43] was used; for SS an antiserum against SS-28 was employed. For *in situ* hybridization, plasmid was linearized, and labeled antisense probes were generated using SP6 RNA polymerase and 35-S-UTP. Sections were dehydrated and exposed to x-ray films, later coated with a liquid autoradiographic emulsion, then finally developed. Cell and grain counting procedures were used to compare the strengths of mRNA signals on autoradiographic material.

Results

The results complement and extend analyses of the previous study, which showed roughly comparable decrements in both SS and GRF-IR in the median eminence of flight animals; though, in this study flight hypophysiotropic fibers were more severely depleted. In comparison to synchronous and tail-suspended animals, the ppGRF mRNA signal in the arcuate nucleus of flight animals was significantly reduced, while ppSS mRNA levels were not significantly altered. While this effect on indices of ppGRF mRNA levels may be representative of an influence exerted at the level of ppGRF gene transcription, alternate explanations (e.g., effects on mRNA stability) cannot be discounted.

Title of Study

Growth Hormone Regulation, Synthesis and Secretion in Microgravity: III. Plasma Analysis Hormone Measurements

Science Discipline

Regulatory Physiology

Investigator	Institute
R.E. Grindeland	NASA-Ames Research Center

Co-Investigator(s)	Institute
Popova, I.A.	Institute of Biomedical Problems
Grossman, E.	NASA-Ames Research Center
Rudolph, I.	NASA-Ames Research Center

Research Subject(s)

Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls

5 Basal, 5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 450; Hardware p. 457

Objectives/Hypothesis

Plasma from space flight and tail-suspended animals was analyzed for a number of constituents in order to evaluate the metabolic status and endocrine function of the specimens. Plasma electrolytes, proteins, glucose nitrogenous products of metabolism, and cholesterol were analyzed, as well as various plasma hormones involved in regulation of calcium metabolism. This experiment was concerned chiefly with plasma hormone measurements.

Approach or Method

Corticosterone, thyroxine, and testosterone were measured by radioimmunoassay using kits. Prolactin and growth hormone were measured by double antibody immunoassays using hormones and antisera prepared at NASA-Ames Research Center. Data were evaluated by analysis of variance.

Results

Corticosterone concentrations varied nearly fourteen-fold between groups, with a level of 3 µg/dl in basal rats, to values of 41 µg/dl in the flight animals, a level similar to that found for highly stressed rats under Earth laboratory conditions. Thyroxine levels were significantly lower in flight rats than in controls and were suggestively lower ($p < 0.08$) than in tail-suspended specimens. The cause of the decreased thyroxine levels is unknown; it appears not to be attributable to either dietary iodine insufficiency or to excessive metabolic demands. A deficit apparently occurs at the thyroid gland, pituitary, or hypothalamic level. Testosterone concentrations were decreased in response to space flight and tail-suspension. The fact that tail-suspended and flight rats both showed decreases in plasma bioassayable growth hormone would argue that the decreased secretion is due to weightlessness and/or hypodynamia and not to re-entry stress.

Title of Study
Histologic Examination of Lung Tissue

Science Discipline
Regulatory Physiology

Investigator	Institute
J.B. West	University of California, San Diego

Co-Investigator(s)	Institute
Mathieu-Costello, O.	University of California, San Diego
Elliot, A.	University of California, San Diego
Kaplansky, A.S.	Institute of Biomedical Problems

Research Subject(s)
Rattus norvegicus (Wistar Rat)

5 Flight Male

Ground-Based Controls
5 Vivarium, 5 Synchronous, 5 Tail-Suspended

Key Flight Hardware
Cosmos 2044 Russian Hardware Suite

More Information
Mission p. 162-8; Publications p. 449; Hardware p. 457

Objectives/Hypothesis
Limited information is available regarding the effect of space flight on the respiratory system. Though animals as small as rats are not expected to undergo major cephalad fluid shifts during microgravity exposure as man does, tail-suspended rats do experience large cephalad shifts in body fluids. This study, through light and electron microscopy, compares the lung tissue of five space-flown rats to tissue from similarly maintained synchronous and tail-suspended animals.

Approach or Method
Within ten minutes of sacrifice, the left lungs were removed and immersed in 3% glutaraldehyde in 0.1 M phosphate buffer. Sections (5-6 µm) taken from a tissue slab cut perpendicular to the cranio-cadual axis just across the most caudal aspect of the hilum were stained with hemotoxin-eosin for light microscopy. Samples for electron microscopy were taken from the most ventral and dorsal aspects of the remaining lower lobe. Sections (1 µm and 50-70 nm), contrasted with uranyl acetate and bismuth subnitrate, were examined for peribronchial cuffing of pulmonary vessels, presence of alveolar edema and general appearance of pulmonary capillaries and parenchyma.

Results
By the onset of dissection, flight animals were inactive and had reddish fluid drops on the tips of their noses, signs attributed to the stress induced by transition into Earth's gravity. No obvious evidence of perivascular cuffing was observed in any group. Red blood cells were seen in the lumen of major airways of all samples, with the least observed in vivarium controls. Pulmonary capillaries appeared more congested in flight animals, possibly related to increased hematocrit due to microgravity. The flight, tail-suspended, and synchronous animals which showed intra-capillary vesicles probably experienced pulmonary hyperintensive episodes which could have induced a hemodynamic form of pulmonary edema.

Title of Study

Biological Rhythm and Temperature Regulation: I. Biological Rhythms and Temperature Regulation

Science Discipline

Regulatory Physiology

Investigator	Institute
C.A. Fuller	University of California, Davis

Co-Investigator(s)	Institute
Alpatov, A.M.	Institute of Biomedical Problems
Klimovitsky, V.Y.	Institute of Biomedical Problems

Research Subject(s)

Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls

2 Synchronous

Key Flight Hardware

Circadian Rhythm/Temperature (CR/T) Experiment Hardware - Modification 1; Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 450; Hardware p. 457, 484-5

Objectives/Hypothesis

This study examined the influence of microgravity on temperature regulation and circadian timekeeping systems in two Rhesus monkeys. Animals were exposed to fourteen days of microgravity while constantly monitoring the circadian patterns, temperature regulation, heart rate and activity. This experiment extended results from Cosmos 1514, as well as providing insights into the physiological mechanisms that produce these changes.

Approach or Method

Four monkeys (3.5-4.0 kg), two serving as ground controls, were implanted with auxiliary temperature/ECG transmitters. The ECG was hardwired; the CR/T equipment received pulses corresponding to R-waves which were sensed and converted to heart rate within the CR/T signal processor. Motor activity rhythms were monitored via piezoelectric sensors attached to the monkey's restraint jacket. Skin sensors recorded temperatures from the ankle, proximal leg, and head. Ambient temperatures at the top and bottom of the primate restraint system were recorded. Data were collected at five-minute intervals and stored on a battery operated logger. Experiment data were transferred to a microcomputer for waveform and period analysis, and storage.

Results

It is clear that circadian rhythms in the various parameters studied persisted in the subjects. However, data indicate that the microgravity environment has a significant influence on both temperature regulation and circadian timing. In general, there is a tendency for a reduction in skin temperatures, and a possible reduction in metabolism and a concomitant reduction in deep body temperature. The circadian timing system appears to be more liable in the microgravity environment, even in the presence of a 24-hour light/dark cycle. Activity-related rhythms appear to be maintained with a 24-hour period, while thermoregulatory rhythms are more variable in the periodic responses and tend to show a greater variability in phase. Observations suggest that the two or more central pacemakers, which compose the circadian timing system, show differential responses to the microgravity environment. Heart rate and motor activity evidence appropriate 24-hour rhythms in a 24-hour light/dark cycle, while the pacemaker for body temperature does not show such stability.

Title of Study

Biological Rhythm and Temperature Regulation: II. Metabolism

Science Discipline

Regulatory Physiology

Investigator	Institute
C.A. Fuller	University of California, Davis

Co-Investigator(s)	Institute
Dotsenko, M.A.	Institute of Biomedical Problems
Korolkov, V.I.	Institute of Biomedical Problems
Stein, T.P.	University of Medicine & Dentistry

Research Subject(s)

Macaca mulatta (Rhesus Monkey)

2 Flight Male

Ground-Based Controls

2 Synchronous

Key Flight Hardware

Cosmos 2044 Russian Hardware Suite

More Information

Mission p. 162-8; Publications p. 450; Hardware p. 457

Objectives/Hypothesis

In this experiment, energy expenditure was measured in Rhesus monkeys using the doubly labeled water ($^{2}H_{2}{}^{18}O$) method. Determinations were made during space flight and during postflight ground control. The doubly labeled water method is the only method available for continuously measuring energy expenditure during space flight considering the severely restricted conditions of spacecraft. Therefore, this study focused on the development and use of this procedure on nonhuman primates during space flight.

Approach or Method

When doubly labeled water is given orally, it mixes with body water in about three hours. The two isotopes then leave the body at different rates; ^{2}H leaves as water, mainly in urine, whereas ^{18}O leaves both as water and exhaled CO_2. Thus the turnover rate of isotopic hydrogen and oxygen labeled differ, the difference proportional to the rate of CO_2 production. Monkeys were dosed (3-5 ml) three days preflight. Urine samples (3 ml) were collected following the dose to determine body water pool size, as well as pre- and postflight. Animals were redosed with ^{18}O postflight to determine any changes in body protein and fat content.

Results

The data from this study demonstrate the viability of this technique as an inflight measure of metabolism, although accuracy could be enhanced by collecting more urine samples. The total body water (TBW) in the flight study of 2.986 corresponds to 77.76% of the animal's body weight, suggesting that the animal was in a dehydrated state when the measurements were made. The flight energy expenditure value of 266 kcal/monkey/day or 69.3 kcal/kg/day appears physiological. Due to a problematic sample, the postflight TBW could not be determined.

Appendix II

EXPERIMENT PUBLICATIONS

Appendix B: Experiment Publications

This appendix lists publications resulting from life sciences flight experiments and related ground-based studies developed or supported by NASA Ames Research Center between 1965 and 1990.

Because of the often long period between a flight experiment and a related publication and the fact that this appendix contains no entries later than the first half of 1994, some current publications may not be included. Peer-reviewed journals have been given preference over conference proceedings, bulletins, etc. These listings are intended to provide a road map for the reader seeking more information and may not be comprehensive.

Frequently, only the first two authors for each publication are included because of space limitations. Citations with more than two authors are listed by first author followed by "et al." to indicate a larger author list for the citation. Additional authors for the experiment typically include those listed as Co-Investigator(s) in Appendix A. The Author Index (p. 599) also reflects this constraint. For comprehensive author lists, locate the original citation (see below).

Publications are grouped by program, mission, experiment reference number, and alphabetically by author, in the corresponding order of the Experiment Descriptions in Appendix A. The unique experiment reference numbers, appearing in the left column, link publications to the corresponding Experiment Descriptions.

Publications may be NASA internal reports or from the open scientific literature. Any publication or abstract identified that focuses on flight experiment results is included. Publications of related ground-based studies are listed together with flight experiment publications, and are indicated by a dagger (†). A related ground-based study is defined as a preflight investigation intended to assist in the definition of a flight experiment or a postflight investigation designed to help interpret or expand flight experiment data.

Readers interested in more information are encouraged to contact Spaceline, a comprehensive Space Life Sciences Bibliographic Database, produced through the cooperative efforts of NASA and the National Library of Medicine, to be available online in early 1995. For information write to:

Spaceline Information
Space Life Sciences Division
Department of Physiology
Uniformed Services
University of the Health Sciences
Bethesda, MD 20814

Grouped by Experiment Reference Number [corresponding page number in brackets]

G3-1 [p.179]

- Anderson, M.: Sea Urchin Fertilization and Development (abstract). BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 139.
- Hacker, B.C.: On the Shoulders of Titans. A History of Project Gemini. NASA SP-4203, 1977.
- Willoughby, R.: Toxicity Problems in Plastic Hardware Designed for Biological Spaceflight Experiments. NASA TM-X-1818, 1969.†
- Young, R.S.: Gravity and Embryonic Development. Life Sciences and Space Research XIV: Proceedings of the Open Meeting of the Working Group on Space Biology, Varna, Bulgaria, May 30-31, 1975, Pergamon Press, 1976, pp. 69–75.
- Young, R.S.: Sea Urchin Fertilization and Development, Experiment S002. Gemini Program Biomedical Science Summary, NASA TM-X-5874, 1971, pp. 245-247.

G8-1 [p.180]

- Anderson, M., ed.: Frog Egg Growth. BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 138.
- Hacker, B.C.: On the Shoulders of Titans. A History of Project Gemini. NASA SP-4203, 1977.
- Tremor, J.W. and R.S. Young: Weightlessness and the Developing Frog Egg. Life Sciences and Space Research VI: Proceedings of the 10th Plenary Meeting of the Working Group V, London, England, July 27-28, 1967, North Holland Publishers, 1968, pp. 87–93.
- Young, R.S. and J.W. Tremor: Frog Egg Growth: Experiment S003. Gemini Program Biomedical Science Summary, NASA TM-X-58074, 1971, pp. 237–244.
- Young, R.S.: Gravity and Embryonic Development. Life Sciences and Space Research XIV: Proceedings of the Open Meeting of the Working Group on Space Biology, Varna, Bulgaria, May 30-31, 1975, Pergamon Press, 1976, pp. 69–75.

G12-1 [p.181]

- Anderson, M.: Frog Egg Growth (abstract). BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 138.
- Tremor, J.W. and R.S. Young: Weightlessness and the Developing Frog Egg. Life Sciences and Space Research VI: Proceedings of the 10th Plenary Meeting of the Working Group V, London, England, July 27–28, 1967, North Holland Publishers, 1968, pp. 87–93.
- Wantanabe, S. et al., eds., Biological Sciences in Space 1986. Proceedings of the 1986 International Symposium on Biological Sciences in Space, MYU Research, 1987.
- Young, R.S. and J.W. Tremor: Frog Egg Growth: Experiment S003. Gemini Program Biomedical Science Summary, NASA TM-X-58074, 1971, pp. 237–244.

† = publication of related ground-based study

Grouped by Experiment Reference Number [corresponding page number in brackets]

- Young, R.S.: Gravity and Embryonic Development. Life Sciences and Space Research XIV: Proceedings of the Open Meeting of the Working Group on Space Biology, Varna, Bulgaria, May 30-31, 1975, Pergamon Press, 1976, pp. 69–75.

BIO2-1 [p.182]

- Browning, L.S.: A Radiation Dose Rate Effect Occurring in Developing Reproductive Cells of Male Drosophila. Drosophila Information Services Research Notes, vol. 45, 1970, pp. 63–64.
- Browning L.S. and E. Altenburg: Effects of the Space Environment on Radiation-Induced Damage in Mature Reproductive Cells of Adult Drosophila and in Spermatocytes of the Immature Testis. Radiation Research, vol. 35, 1968, pp. 500–501.
- Browning, L.S. and E. Altenburg: Effects of the Space Environment on Radiation-Induced Damage in the Reproductive Cells of Pupal and Adult Drosophila. Japanese Journal of Genetics, vol. 43, 1968, pp. 461–462.
- Browning, L.S. and E. Altenburg: Genetic Effects of the Space Environment on the Reproductive Cells of Drosophila Adults and Pupae. BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 101.
- Browning, L.S. et al.: Mutational Responses of Insects in the Biosatellite II Experiment. Life Sciences and Space Research: Proceedings of the 11th Plenary Meeting, Tokyo, Japan, May 14-16, 1968, North Holland Publishing, 1969, pp. 70–76.
- Browning, L.S.: Genetic Effects of the Space Environment on the Reproductive Cells of Drosophila Adults and Pupae. The Experiments of Biosatellite II. NASA SP-204, 1971, pp. 55–78.

BIO2-2 [p.183]

- Oster I.I. and D.E. Good: Irradiation of Drosophila Under Spaceflight Conditions. Radiation Research, vol. 35, 1968, p. 500.
- Oster, I.I.: Genetic Effects of Zero Gravity and Radiation. Japanese Journal of Genetics, vol. 43, 1968, pp. 462–463.
- Oster, I.I.: Genetic Effects Produced by the Space Environment. Life Sciences and Space Research: Proceedings of the 12th Plenary Meeting, Prague, Czechoslovakia, May 11-14, 1969, North Holland Publishing, 1970, pp. 95–96.
- Oster, I.I.: Genetic Implications of Spaceflight. BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 127.
- Oster, I.I.: Genetic Implications of Spaceflight. The Experiments of Biosatellite II, NASA SP-204, 1971, pp. 41-54.

BIO2-3 [p.184]

- Grosch, D.S.: Egg Production and Embryo Lethality for Habrobracon from Biosatellite II and Associated Postflight Vibration Experiments. Mutation Research, vol. 9, 1970, pp. 91–108.
- Grosch, D.S. et al.: Biological Responses of Habrobracon to Spaceflight. Life Sciences and Space Research: Proceedings of the 12th Plenary Meeting, Prague, Czechoslovakia, May 11-14, 1969, North Holland Publishing, 1970, pp. 6–11.

† = publication of related ground-based study

Grouped by Experiment Reference Number [corresponding page number in brackets]

- Grosch, D.S.: Reproductive Performance of Female Braconids Compared after Brief and Protracted Exposure to Ionizing Radiations. Isotopes and Radiation in Entomology, International Atomic Energy Agency (Vienna), 1968, pp. 377–390.
- Grosch, D.S.: The Utilization of Habrobracon and Artemia as Experimental Materials in Bioastronautic Studies. Final Report, NASA CR-114590, 1972.
- von Borstel, R.C. et al.: Experiments with Habrobracon and Tribolium on Biosatellite II. Japanese Journal of Genetics, vol. 63, 1968, p. 464.
- von Borstel, R.C. et al.: Mutational and Physiologic Responses of Habrobracon. BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 135.
- von Borstel, R.C. et al.: Mutational and Physiological Responses of Habrobracon in Biosatellite II. The Experiments of Biosatellite II, NASA SP-204, 1971, pp. 17–39.
- von Borstel, R.C. et al.: Mutational Responses of Insects in the Biosatellite II Experiment. Life Sciences and Space Research: Proceedings of the 11th Plenary Meeting, Tokyo, Japan, May 14-16, 1968, North Holland Publishing, 1969, pp. 70–76.
- von Borstel, R.C. et al.: The Habrobracon Experiment in the Biosatellite II Spacecraft. Radiation Research, vol. 35, 1968, p. 501.

BIO2-4 [p.185]

- de Serres, F.J. and B.B. Webber: Genetic Effects of 85Sr Irradiation on Neurospora crassa. Radiation Research, vol. 35, 1968, pp. 436–444.
- de Serres, F.J. and B.B. Webber: Mutagenic Effectiveness of Known Doses of Radiation in Combination with Zero Gravity on Neurospora. BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 160.
- de Serres, F.J. and B.B. Webber: The Induction of Recessive Lethal Mutations Under Weightlessness in the Neurospora Experiment on the Biosatellite II Mission. Radiation Research, vol. 43, 1970, pp. 452–459.
- de Serres, F.J.: Effects of Radiation During Spaceflight on Microorganisms and Plants on the Biosatellite II and Gemini 11 Missions. Life Sciences and Space Research: Proceedings of the 11th Plenary Meeting, Tokyo, Japan, May 14-16, 1968, North Holland Publishing, 1969, pp. 62–66.
- de Serres, F.J.: Effects of Weightlessness on Simple Life Forms in Biosatellite II. Federation of American Society for Experimental Biology, 56th Annual Meeting, Atlantic City, N.J., April 9, 1972, Conf-720441, 1972, p. 8.
- de Serres, F.J.: Effects of Weightlessness on Simple Life Forms in Biosatellite II. The Physiologist, vol. 16, 1973, pp. 225–228.
- de Serres, F.J.: Mutagenic Effectiveness of Known Doses of Radiation in Combination with Zero Gravity on Neurospora crassa. The Experiments of Biosatellite II, NASA SP-204, 1971, pp. 325–331.
- de Serres, F.J.: Neurospora Experiment P-1037. Final Report, NASA CR-112355, 1970.

† = publication of related ground-based study

Grouped by Experiment Reference Number [corresponding page number in brackets]

- Saunders, J.F. et al.: The Experiments of Biosatellite II. S.A. Gordon and M.J. Cohen, eds., Gravity and the Organism, University of Chicago Press, 1971, pp. 443–450.

BIO2-5.1 [p.186]

- Abel, J.H. et al.: Effects of Weightlessness on the Nutrition and Growth of Pelomyxa carolinensis. BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 95.
- Abel, J.H. et al.: Effects of Weightlessness on the Nutrition and Growth of Pelomyxa carolinensis. The Experiments of Biosatellite II, NASA SP-204, 1971, pp. 291–308.
- Price, R.W. and J.H. Abel: The Effects of Weightlessness on Pelomyxa: III. Digestion, Growth, and Locomotion. Bioscience, vol. 18, no. 6, 1968, pp. 622–632.

BIO2-5.2 [p.187]

- Eckberg, D.R.: Biosatellite Controlled Experiments Requirements and Nature, Noting Flight Weightlessness, Radiation, and Biological Rhythm Effects. British Interplanetary Society Journal, vol. 21, 1968, pp. 148–153.
- Eckberg, D.R. et al.: Nuclear and Cellular Division in Pelomyxa carolinensis During Weightlessness. BIOSPEX: Biological Space Experiments, NASA TM-58217, 1979, p. 103.
- Eckberg, D.R. et al.: Nuclear and Cellular Division in Pelomyxa carolinensis During Weightlessness. The Experiments of Biosatellite II, NASA SP-204, 1971, pp. 273–290.
- Eckberg, D.R. et al.: The Effects of Weightlessness on Pelomyxa: II. Nuclear and Cellular Division. Bioscience, vol. 18, no. 6, 1968, pp. 617–622.

BIO2-6 [p.188]

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C2044-28 [p.388]

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† = publication of related ground-based study

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† = publication of related ground-based study

Appendix III

HARDWARE DESCRIPTIONS

Appendix III: Flight Hardware

This appendix profiles flight hardware used in life science experiments flown by NASA ARC between 1965 and 1990.

Hardware items are listed alphabetically. The mission on which the hardware was flown is indicated for each item.

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A listing of U.S.S.R.-built hardware used in the Cosmos missions and references from Soviet reports/journals are provided. This hardware is not individually described in this appendix since it was not developed by NASA. A brief description of many of these items can be found in of Section 4.24, The Cosmos Biosatellite Program (p. 118). A listing of each of these items and appropriate bibliographic references also appear on the following pages.

The appendix includes:

- **Key U.S.-built flight hardware**
  -major subsystems for each hardware item are listed in italics and indicated by an asterisk (*), and are described in more detail in separate entries
  -minor subsystems are listed in bold and briefly described for each hardware item, but do not appear as separate entries
- **Related ground-based hardware** (items necessary for flight hardware operation)
- **Modified flight hardware**
  -hardware items modified for reuse on subsequent missions are designated Modification 1, etc. and described in separate entries

Flight hardware information was obtained from the open literature, NASA internal reports, and NASA hardware design reviews.

Each U.S. flight hardware entry contains: a description of the flight hardware item and appropriate subsystems; references to documents and publications from which the information was derived; a listing of general specifications (when available); a brief description of any related ground-based hardware; means of data acquisition (if applicable); and a full-page labelled illustration. Figures in this appendix are not scale drawings, but are intended to assist the reader in understanding the general design and operation of the hardware.

For further information regarding recent flight hardware, please contact the Flight Equipment Engineering Branch of the Space Life Sciences Payloads Office, NASA-Ames Research Center, Moffett Field, CA, 94035-1000, phone (415) 604-6483.

Cosmos 782/936 U.S.S.R. Hardware Suite (hardware used by U.S. experiments)

- Rodent Cages (individual housing)
  -feeding/watering
  -lighting
  -waste management
- Fish Embryo Case (Fundulus chambers)
- Fruit Fly Containers (Drosophila chambers)
- Biotelemetry System
  -rodent physiological sensors
  -transmitter
- Flight Centrifuges

Biolocheskiye Issledovaniya na Biosputnikakh 'Kosmos' (Biological Studies on the Kosmos Biosatellites). E.A. Ilyin and G.P. Parfenov, eds. Moscow: Nauka, 1979. NASA TM-75769 [hardware and selected results from Cosmos 605, 690 782, 936]

Vliyaniye Dinamicheskikh Factorov Kosmicheskigo Poleta na Organism Nhivotnykh (The Effect of Dynamic Factors of Spaceflight on Animal Organisms). A.M. Genin, ed. Moscow: Nauka, 1979. NASA TM-75692 [hardware and selected results from Cosmos 605, 690, 782, 936]

Gazenko, O.G. et al.: Principal Results with Mammals Onboard the Kosmos-782 Biosatellite. *Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina*. Vol. 12 (No. 6): 43-49, 1978.

Kotovskaya, A.R. et al.: Soviet Investigations of Artificial Gravity. *Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina*. Vol. 15 (No. 2): 72-79, 1981.

Cosmos 1129 U.S.S.R. Hardware Suite (hardware used by U.S. experiments)

- Rodent Cages (individual housing, same as Cosmos 782/936 Rodent Cages)
- Rodent Mating Chamber (group housing)
  -feeding/watering
  -lighting
  -waste management
  -moveable partition
- Quail Egg Incubator

Ilyin, E.A.: Investigations on Cosmos Biosatellites. *Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina*. Vol. 18 (No. 1): 57-66, 1984. [general information concerning Cosmos 605 through 1129]

Cosmos 1514 U.S.S.R. Hardware Suite (hardware used by U.S. experiments)

- Primate BIOS Capsules
  -restraint couches
  -feeding (paste)/drinking (juice) systems
  -waste management
  -monitoring camera
  -primate physiological sensors
  -biotelemetry system
- Psychomotor Test System
  -light signal stimuli
  -foot lever (with EMG monitoring)
  -eye-tracking device
- Rodent Cages (individual housing, same as Cosmos 1129 Rodent Cages)
- Rodent BIOS Chamber (group housing, modification of Rodent Mating Chamber by removal of partition)

Melnichenko, V.P. et al.: Electrocardiography in the Neb-Type Leads in Macaca mulatta. *Kosimcheskaya Biologiya i Aviakosmicheskaya Meditsina.* Vol. 19 (No. 6): 87-90, 1985.

Serova, L.V. et al.: Experimental Conditions on the Kosmos-1514 Biosatellite. *Ontogenez Mlekopitayuschikh v Nevesomosti* (Ontogenies of Mammals in Microgravity), Moscow: Nauka Press: 37-38, 1988. See also NASA TM #103978.

Cosmos 1667 U.S.S.R. Hardware Suite (hardware used by U.S. experiments)

- Primate BIOS Capsules (same as Cosmos 1514 Primate BIOS Capsules)
- Psychomotor Test System

Magedov, V.S. and Yu.S. Koryakov: Special Equipment of Magnetic Recording of Physiological Information Obtained in Biosatellite Studies. *Kosimicheskaya Biologiya i Aviakosmicheskaya Meditsina.* Vol. 20 (No. 4): 79-81, 1986.

Gazenko, O.G. et al.: Rat Experiments on the Biosatellite Cosmos 1667: Goals, Protocols, Results. *Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina*. Vol. 21 (No. 4): 9-16, 1987. [U.S. did not participate in rodent experiments on Cosmos 1667]

Cosmos 1887 U.S.S.R. Hardware Suite (hardware used by U.S. experiments)

- Primate BIOS Capsules (same as Cosmos 1514 Primate BIOS Capsules)
- Rodent BIOS Chamber (group housing, same as Cosmos 1514 Rodent BIOS Chambers)

Kovalev, E.E. et al.: Space Flight Radiation Safety in the InterCosmos Program. *Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina.* Vol. 22 (No. 6): 36-41, 1988. [radiation studies throughout Cosmos program, including U.S. investigations]

Ilyin, E.A.: Cosmos Biosatellites: Results and Perspectives of Investigations. *Kosmicheskaya Biologiya i Aviakosmicheskaya Meditisina.* Vol. 22 (No. 6): 41-51, 1988. [focuses on Cosmos hardware up through Cosmos 1667]

Cosmos 2044 U.S.S.R. Hardware Suite (hardware used by U.S. experiments)

- Rodent BIOS Chamber (group housing, same as Cosmos 1887 Rodent BIOS Chambers)
- Primate BIOS Capsule (same as Cosmos 1887 Primate BIOS with modified food nozzle)
- Gaze Fixation Equipment (modification of Cosmos 1514/1667 Psychomotor Test System)
  -ocular electrodes (for recording horizontal oculogram)
  -vestibular nuclei activity recording device
  -head movement sensor
  -light signal stimuli

Gazenko, O.G. et al.: Habitability and Biological Life Support Systems. *Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina*. Vol. 24 (No. 3): 12-17, 1990.

Golov, V.K. et al. Hardware Support of Experiments. *Cosmos 2044 Biosatellite Description and U.S. Final Reports of Monkey and Rat Experiments.* J.P. Connolly, R.E. Grindeland and R.W. Ballard, eds. NASA TM #108802, September, 1994.

U.S. Flight Hardware Descriptions and Figures

Animal Enclosure Module (AEM)

Hardware Description

The Animal Enclosure Module (AEM) supports up to five 250 g rats and fits inside a standard middeck locker with a modified locker door. It is composed of a stainless steel grid cage module, fan blowers, a layered filter system, interior lamps, and a water unit; food bars are glued on cage walls. Total animal floor space, with water box installed, is 645 cm^2. A removable divider plate provides two separate animal holding areas (if required). The AEM remains in the stowage locker during launch and landing. In orbit the AEM may be removed from the locker and the interior viewed or photographed through the clear Lexan cover over the cage; the AEM must be pulled out of the locker approximately three quarters of its depth for observation of the rodents. Temperature can be read from a built-in thermometer and recorded automatically when the AEM is outfitted with a 4-Channel Ambient Temperature Recorder (ATR-4). A main breaker protects and distributes power to fan and lighting subsystems. Additional circuit breakers independently protect lights and fans in diagonally opposed corners to assure light and air circulation on each side of the AEM should one breaker fail. The AEM can be moved into the Orbiter approximately twelve hours before launch and removed approximately one hour after landing. The original AEM unit was developed for the Student Shuttle Flight Program (SSIP) by the General Dynamics Company. Units flown initially utilized potatoes as a water source.

Air Quality: Cabin air is exchanged with the unit through a filter system. Four fan blowers, operated by a switch on the front panel, create a slight negative pressure inside the cage, causing an air sweep to pull animal waste products into a collection filter. Cabin air is drawn through the front panel inlet slots, then along the side plenum walls, to be directed though the inlet filter located at the rear of the AEM, into the animal habitat. High efficiency particulate air filters (electrostatic and phosphoric acid treated fiberglass pads) prevent any microbiological escape into the cabin atmosphere. Treated charcoal, within the unit, confines animal odors within the closed system. After exiting the habitat through the exhaust filter, located at the front of the unit between the rodent cage and fans, the filtered air is drawn through the fans into the cabin and directed by the air deflector. Air flow indicator ribbons are attached to both sides of the air deflector for visual confirmation of AEM air flow.

Lighting: The four internal lamps provide an average of 14 lux illumination and are controlled by an automatic timer to provide a twelve-hour lighting cycle. The lamps are mounted two to a side in the rear corners of the AEM, between the animal habitat and inlet filter, and are covered with a clear cap to protect each lamp from animal debris. Although the twelve-hour cycle is fixed, the starting hours, minutes, and day/night sequence can be selected.

Water: The unit has a 1,500 and 2,000 cc capacity automatic watering unit that utilizes four "Lixit Drinking Valves" and two flexible plastic (polyvinylchloride) bladders for water storage. Sufficient water pressure is maintained via compression springs. Total water consumption can be monitored inflight by observation of water levels via a Lexan window on the top of the water box.

Food: Rodent food bars are attached to four slide-in food bar plates inside the rodent cage. The food, a sterilized laboratory formula, is molded into rectangular bars (approximately 1.8 x 1 x 8 inches) accessible to the animals at all times during the mission.

Specifications

Dimensions:	24.50 x 43.69 x 51.05 cm
Weight:	27.2 kg (with food, water, and rats)
Power:	35.5 W (min), 46.5 W (max)
Temperature:	Elevated 3-8 °C above orbiter middeck or Spacelab cabin (four internal fans circulate air through the AEM from the cabin)

Data Acquisition

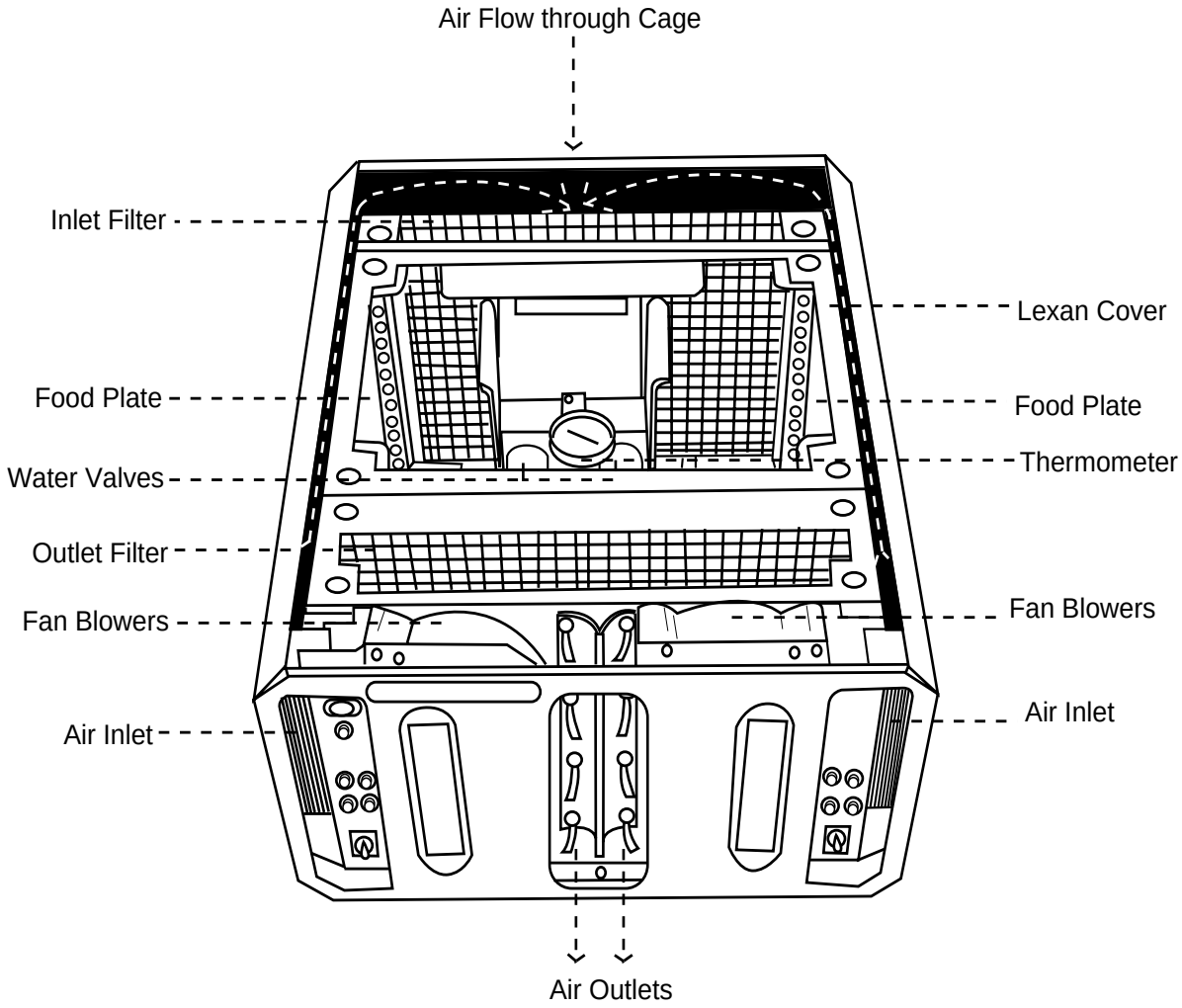
Water consumption data (monitored by crew)

Related Ground-Based Hardware

None

Publications

- Brooks, K. *Spacelab Life Sciences 1: Animal Enclosure Module (AEM) Crew Training Workbook/Familiarization Manual.* NASA Ames Research Center, Space Life Sciences Payloads Office, 1981.
- *Life Sciences Laboratory Equipment Catalog.* NASA Ames Research Center, Space Life Sciences Payloads Office, May 1989, p. 3.
- Morey-Holton, E.R., et al. *NASA Newsletters for the Weber Student Shuttle Involvement Project.* NASA TM-101001, November 1988.



Missions Flown Through 1990:STS-8/SSIP (p. 112), STS-10(41B)/SSIP (p. 112), STS-29/SSIP (p. 113), STS-41/PSE (p. 109)

Hardware Description

The BIOCORE (BIOlogical COsmic Ray Experiment) Life Support Hardware consists of a flight canister which contains six mouse tubes and a tube of potassium superoxide (KO_2), the latter of which provides necessary oxygen and absorbs carbon dioxide. The BIOCORE hardware package measures 35.6 cm long, has a diameter of 17.8 cm, and is designed to fit inside an Apollo storage locker (17.8 x 22.9 x 38.1 cm). No interfaces with the spacecraft subsystems, such as electric power, data acquisition, or cabin atmosphere, are required or were available on the Apollo XVII flight. As a closed, self-sustaining system, the canister and spool fixture house the KO_2 tube and mice in a manner that facilitates feeding and movement despite the tendency to free float.

Flight Canister and Spool: A hermetically sealed aluminum canister (29.0 cm long and 17.7 cm in diameter) contains an aluminum spool fixture, six mouse tubes circumferentially arranged around the spool, and a centrally located KO_2 tube. The KO_2 and mouse tubes can be removed from the canister for cleaning and for reloading of the KO_2. Two manually controlled purge valves for flushing out the canister and two pressure relief valves, set to maintain the package at 284 to 388 mm Hg (5.5 to 7.5 psi) above the ambient pressure, are provided. A purge tube attached to the end cap carries the oxygen to the closed end of the canister to assure ample purging of the air in the canister during experiment startup. Between the relief valves and canister atmosphere is a 1.6 mm thick Teflon felt filter and a fiberglass high-efficiency particulate air filter to prevent the release of microorganisms and dust particles when the canister vents into the spacecraft atmosphere. An aluminum shield is installed over the valves to protect them and support the canister in the locker. A 0.76 mm thick gasket (90% indium and 10% silver) is placed between canister end and spool-tube assembly. Five small leaf springs, located around the periphery of the canister end cap, press against the flange of the spool. Two 1.3 cm wide aluminum blocks, cemented to the canister side, press against a sidewall of the locker, and the canister end opposite the shield presses against one endwall of the locker.

Mouse Tube: Pocket mice are aggressive and must be individually housed. Each mouse is maintained in a 2.9 cm-diameter metal tube with an inside diameter slightly larger than the mouse (2.54 cm), permitting it to turn about. Each of the 1.6 mm-thick aluminum tubes runs the full length of the canister. The tubes, which house the mice and their food, are perforated with 546 holes (1.57 mm diameter) sized to retain the smallest seeds. Thirty grams of food (equal parts by volume of hulled sunflower, rye, oat groats, and millet seeds) are placed in each of the six tubes. A water supply system is not required since the mice produce water metabolically from their food. Two small maximum/minimum temperature recorders are located in the end caps of two of the mouse tubes.

KO_2 Tube: The KO_2 is located in the center of the spool in a 6.25 cm diameter stainless steel tube that also runs the full length of the canister. The 1.59 mm thick tube, which contains 530 g of KO_2, is perforated with 228 holes (4.0 mm diameter) to provide the desired rate of gas transport to and from the KO_2. A 1.60 mm layer of Teflon felt covers the tube, and a fine mesh stainless steel screen is wrapped around over the felt to provide a particle barrier between the KO_2 and the mice.

Specifications

Dimensions:	35.6 (length) x 17.8 cm (diameter)
Weight:	6.1 kg
Power:	None
Mouse Tube:	2.9 cm (diameter), 1.6 mm (thick)
KO_2 Tube:	6.25 cm (diameter),1.59 mm (thick)
Oxygen Partial Pressure:	~83 x 10^3 N/m^2 (12 psi), maximum estimate
Mouse Tube Temperature:	28 °C, maximum estimate

Data Acquisition

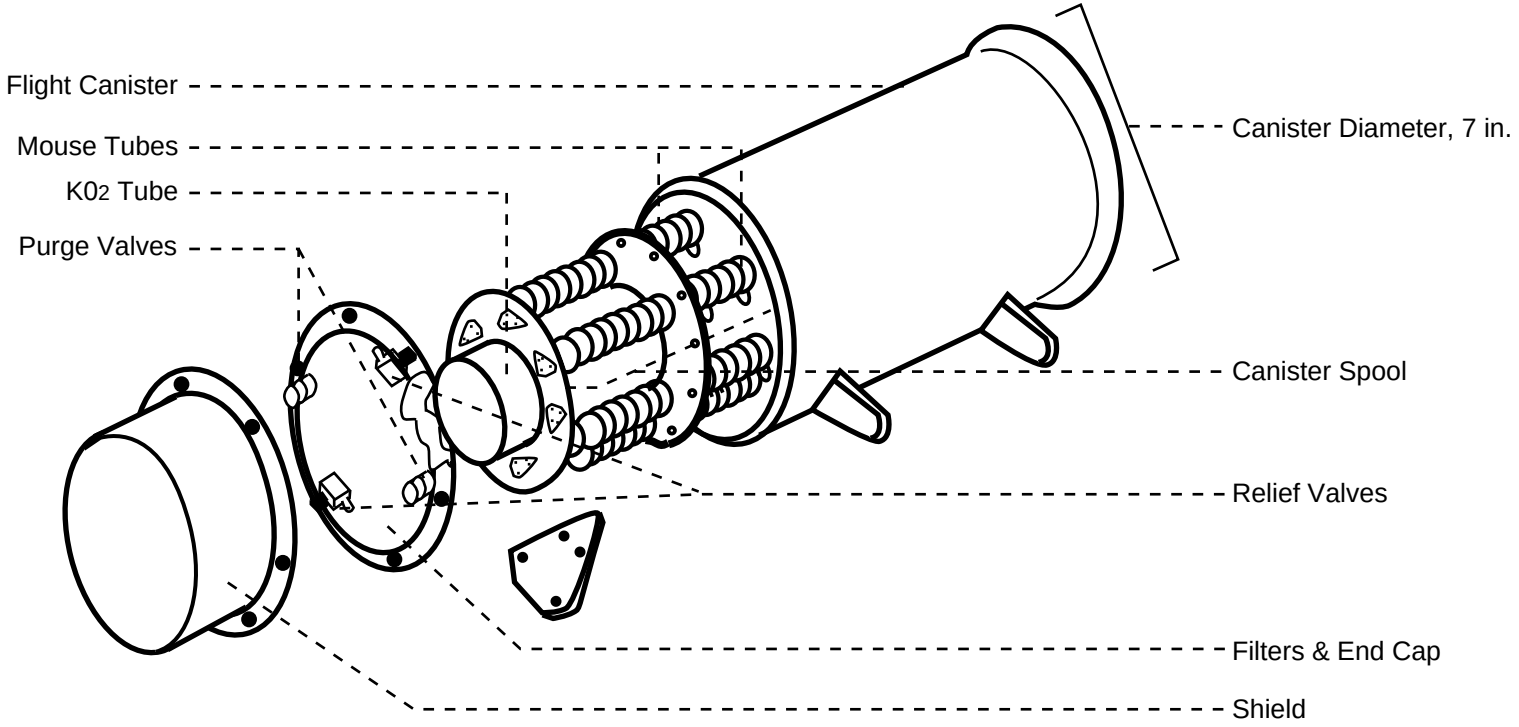
Temperature maximum/minimum

Related Ground-Based Hardware

Recovery Ventilating System: To ensure oxygen partial pressure during transport is below that which would cause lung damage. A pressurized bottles of gas mixture (50% O_2, 50% He), a pressure flow regulator and pressure gage are assembled in a carrying case that also accommodates the canister. After removal from Apollo, the flight canister is installed in ventilator carrying case and purged with gas mixture continuously until ready for opening at laboratory.

Publications

- Haymaker, W., et al.: The Apollo 17 Pocket Mouse Experiment. *Biomedical Results of Apollo,* R.S. Johnston, L.F. Dietlein, C.A. Berry, eds., NASA SP-368, 1975, pp. 381–403.
- Look, B.C., et al. The Effects of Cosmic Particle Radiation on Pocket Mice Aboard Apollo XVII: Engineering Aspects of the Experiment and Results of Animal Tests. *Aviation, Space and Environmental Medicine,* vol. 46, no. 4, 1975, pp. 500–520.
- Look, B.C., et al., The Effects of Cosmic Particle Radiation on Pocket Mice Aboard Apollo XVII: VI. Launch, Flight, and Recovery. *Aviation, Space and Environmental Medicine,* vol. 46, no. 4, 1975, pp. 529–536.



Missions Flown Through 1990:Apollo 17 (p. 71)

BIOCORE: Pocket Mouse Radiation Dosimeter

Hardware Description

The BIOCORE (BIOlogical COsmic Ray Experiment) Pocket Mouse Radiation Dosimeters are designed to record the trajectories of HZE cosmic ray particles passing through the heads of the mice to monitor injury to the brain and the eyes. For the dosimeter to retain its position beneath the scalp, it was necessary to develop a platform on which the dosimeter could be mounted to the skull.

Radiation Dosimeter: The particle detector is composed of four layers of plastic, the outer two layers of Lexan polycarbonate, and in between, two layers of cellulose nitrate (CN). The outer edges of the two Lexan layers are heat sealed, encasing the CN layers to form a rigid, compact dosimeter. The original surface area of the dosimeter is approximately 65 mm^2, while the usable (original less heat sealed) area for particle monitoring is 55 mm^2. From testing with experimental LET values, it was determined that cosmic ray particles with Z £ 8 which first register in the plastics are likely to have stopped before reaching the head. The dosimeter coated with 0.04-0.04 mm Paralene C for protection against tissue fixatives. The dosimeter is designed to cover the entire brain from the olfactory bulbs anteriorly to the cerebellum posteriorly. The plastics are chemically etched postflight to render latent tracks produced by the passage of high-LET particles microscopically visible. For tracing trajectories into the heads, each particle trajectory in the flight mouse dosimeters was angularly measured with a stereotaxic apparatus, charted manila dosimeter mock-ups, and replicated on a control mice using a drill or needle.

Dosimeter Platform: The dosimeter is mounted on a custom platform, the underside of which is contoured to the skull. Platforms are cast in a mold prepared from the the upper part of the tar- get skull. The front part of the platform is cut even with the front of the dosimeter. Platforms are constructed so as to minimize the distance between the dosimeter and skull. Maximum distance from the under surface of the most posterior part of dosimeter to the skull is 1 mm; the shortest distance between the dosimeter and the eyes is 1.38 mm. The assembly is implanted beneath the mouse scalp, where scalp tension fixes its position with respect to the skull.

Specifications

Dimensions:	7.0 x 13.8 x 0.5842 mm
Weight:	Unknown
Power:	None
Surface Area:	65 mm^2 (55 mm^2 usable)
Thickness (Lexan):	0.19 mm (each layer)
Thickness (CN):	0.11 mm (each layer)

Data Acquisition

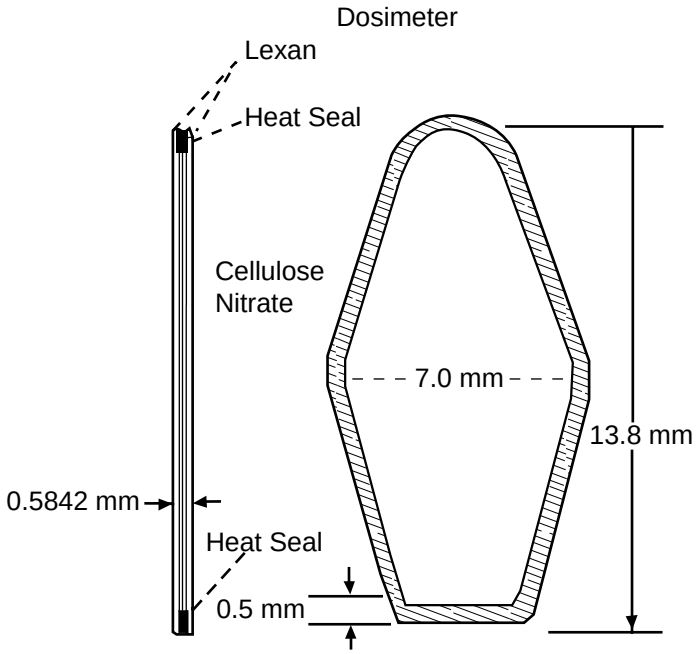
Radiation particle trajectory data

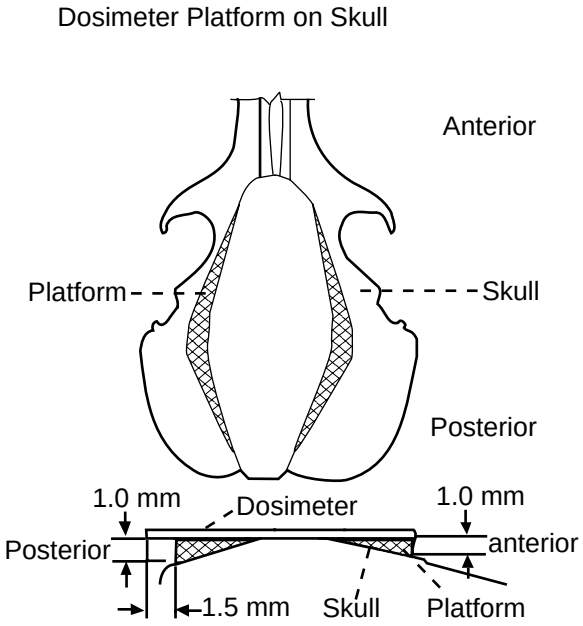
Related Ground-Based Hardware

Mounting Boxes: Made of anodized aluminum. Head is supported by tapered bars inserted into each external auditory meatus, a jaw bar for snout, and a nose clamp.
Stereotaxic Apparatus (SA): For rotation and tilt of mounting boxes in tracing cosmic ray particles.
Laser System: For adjustment of box grid, so the plane of the dosimeter is parallel with the (horizontal) plane of the SA; SA micrometer (tilt) readings constitute data relative to angular orientation of dosimeter plane.

Publications

- Haymaker, W., et al., The Apollo 17 Pocket Mouse Experiment. *Biomedical Results of Apollo,* R.S. Johnston, L.F. Dietlein, C.A. Berry, eds., NASA SP-368, 1975, pp. 381–403.
- Winter, D.L., et al. The Effects of Cosmic Particle Radiation on Pocket Mice Aboard Apollo XVII: III. Dosimeter Design, Construction and Implantation. *Aviation, Space and Environmental Medicine*, vol. 46, no. 4, 1975, pp. 494-499.
- Cruty, M.R., et al., The Effects of Cosmic Particle Radiation on Pocket Mice Aboard Apollo XVII: VII. Cosmic Ray Particle Dosimetry and Trajectory Tracing. *Aviation, Space and Environmental Medicine,* vol. 46, no. 4, 1975, pp. 537-552.





Missions Flown Through 1990:Apollo 17 (p. 71)

Biotelemetry System (BTS)

Hardware Description

The Biotelemetry System monitors physiological functions of mammals onboard the Spacelab. This rack-mounted system is designed to be used primarily with the Research Animal Holding Facility (RAHF). Each unit of the BTS can monitor one animal for one to four physiological parameters. The BTS consists of three basic parts: 1) the implantable sensor and transmitter within the animal; 2) the antenna/receiving system incorporated with the RAHF; and 3) the data-handling system onboard the Spacelab. Transmission of data from the BTS data-handling system to Spacelab data systems is accomplished through a Life Sciences Laboratory Equipment (LSLE) Microcomputer.

Implantable Sensors and Transmitter: The implants for SL-3 included a transmitter as well as the sensors for deep-body temperature and heart rate (ECG). Other measurable parameters include pressures (aortic, arterial, left and right ventricle), EOG and EMG. The range of the transmitter is at least one foot. Implantation typically occurs three weeks prior to launch.

Antenna/Receiving System: The antenna is capable of being installed within one cage of the RAHF, connected via cables to a receiver compatible with the BTS Data Handling System. Sensor data are telemetered to antennae within selected rodent cages and primate cages, and routed to the BTS receiver/demodulators through antennae lead-in cables. A pulse interval modulated FM radio signal is received from each animal cage being monitored.

Data Handling System: The animal ECG rate is up to 320 samples/second; the other parameters are sampled one/second by the LSLE Microcomputer. Data can be stored or downlinked to Earth by radio transmission in realtime or near-realtime.

Life Sciences Laboratory Equipment (LSLE) Microcomputer: The LSLE Microcomputer is designed as a stand-alone computer for use with flight experiments onboard the Shuttle. A flex- ible system design allows the experimenter to use the microcomputer to accomplish a variety of experiment computer operations, by interfacing with Spacelab data systems for telemetry and/or onboard interaction. It is designed to assemble and format data into uniform major and minor frames for transmission through the Shuttle high rate multiplexer (HRM) to the ground. For the SL-3 mission the microcomputer assembled, formatted and time-coded the BTS data for HRM transmission, after converting the signal from analog to digital. It operated only during orbit, and was activated by the crew via a front panel switch.

Specifications

Dimensions: 48 x 35 x 18 cm
Weight: 15.89 kg
Power: 43 W
Sensors: Body Temperature, ECG
Signal: Continuous FM radio signal

Data Acquisition

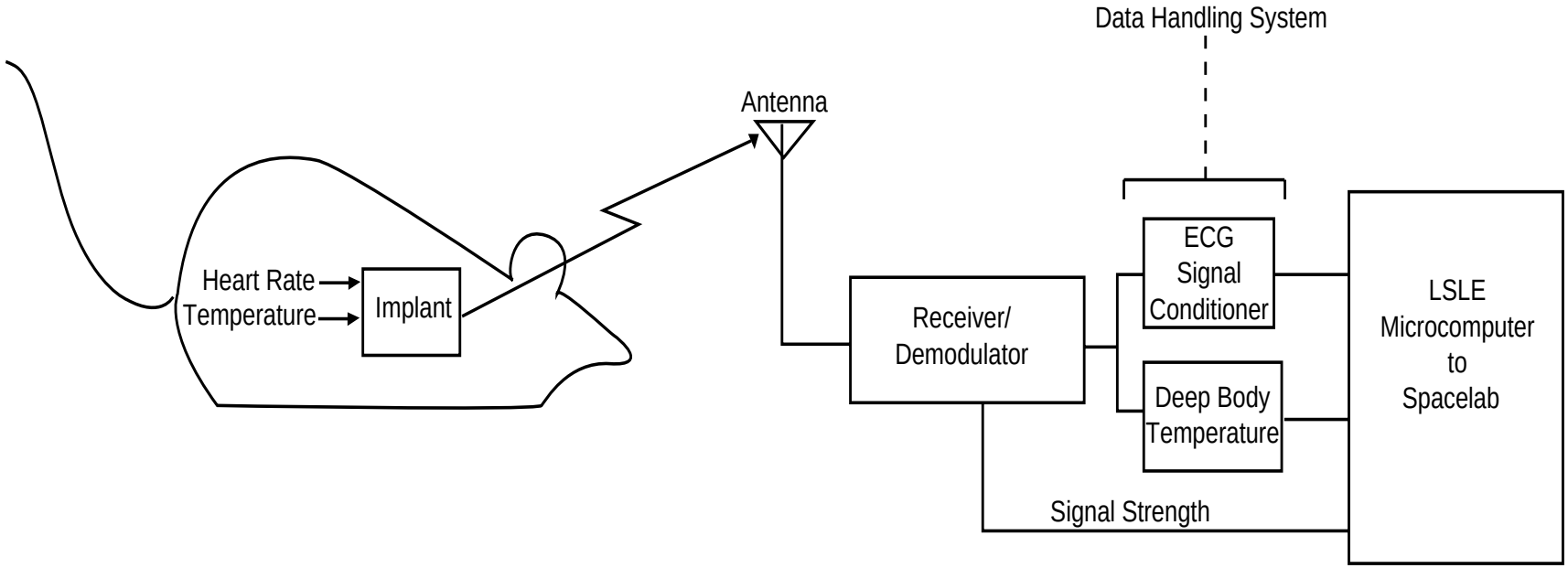
Deep-body temperature and heart rate data

Related Ground-Based Hardware

Experiment Data Interface System: Ground interface to HRM signal for creating graphic display screens of BTS data during the flight.

Publications

- *Ames Research Center, Life Sciences Payload, Spacelab-3, 60 Day Report*. P.X. Callahan,ed., NASA Ames Research Center, Space Life Sciences Payload Office, April 1985.
- *Life Sciences Laboratory Equipment Catalog.* NASA Ames Research Center, Space Life Sciences Payloads Office, May 1989, p. 5.



Missions Flown Through 1990:STS-51B/SL-3 (p. 92)

Hardware Description

The Capsicum (pepper plant) Experiment Package contains nine plants potted in plastic containers. Four of the plants are photographed inflight to record leaf movement, the remaining five are analyzed postflight. The photography package consists of a camera positioned in the center of four plants with a three-mirror optical system to photograph the plants from the side and top at ten minute intervals throughout the flight. Illumination for the plants and photography is provided by four 15 Watt incandescent lamps which produce 200 foot candles of light for five seconds every ten minutes. A realtime clock is inserted between the top central mirrors so that each frame of the film shows the angles of the leaves as well as their position with respect to time. During flight the unit is covered with a white sleeve to provide for maximum utilization of light and to prevent light leakage into the Biosatellite capsule. A series of small holes in the sleeve allows for air exchange.

Capsicum (Pepper Plant) Experiment Package

Specifications

Dimensions: 10 in (height), ~1 cu ft (volume)
Weight: 12 lbs
Power: Unknown
Irradiance: 200-foot candles

Data Acquisition

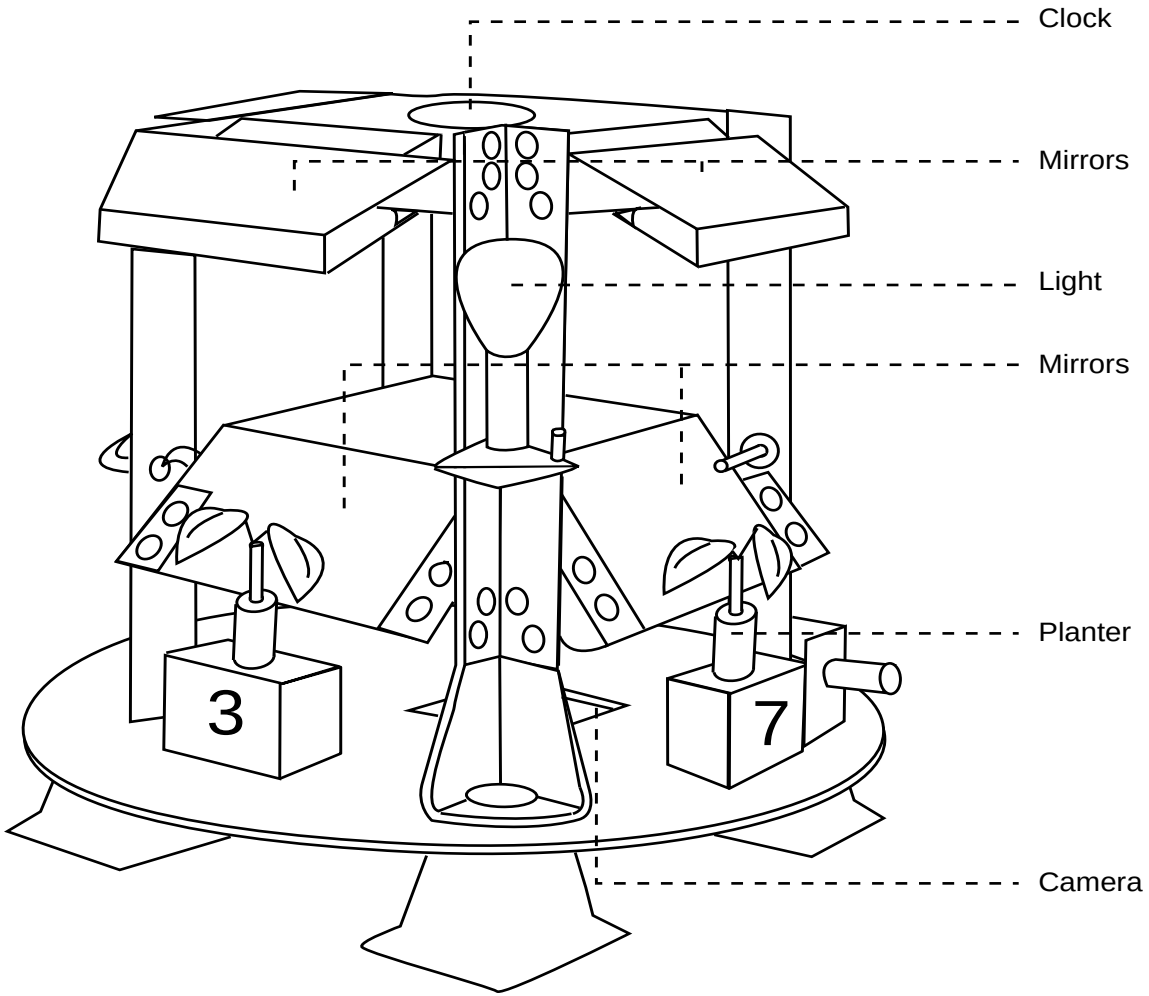
Photographic documentation

Related Ground-Based Hardware

None

Publications

- Johnson, S.P and T.W. Tibbitts: The Liminal Angle of a Plagiogeotropic Organ Under Weightlessness. *Bioscience*, vol. 18, no. 106, June 1968, pp. 655–661.
- *Biosatellite Project Historical Summary Report.* J.W. Dyer, ed., NASA TM-X-72394, December 1969.



Missions Flown Through 1990:Biosatellite I/II (p. 46)

Hardware Description

Each cardiovascular monitoring system consists of a cuff for measuring pressure and flow, a signal conditioner, and a timer/controller apparatus.

Combined Pressure/ Flow (CPF) Cuff*: Both flow and pressure transducers are contained within a single cylindrical molded cuff that is placed around the carotid artery of the Rhesus monkey. The leads pass under the skin and exteriorize at the monkey's lower back.

Signal Conditioners: The U.S. signal conditioner accepts a "start pulse" from the Biosatellite on reaching orbit to become activated and also to transmit pressure and flow signals to the onboard Soviet tape recorder. Two cardiovascular signal conditioners are used: one measures pressure and flow from the CPF Cuff implanted in the primate; a second unit (along with a separate CPF Cuff) measures capsule ambient pressure to provide a correction and normalization for the im- planted pressure sensor to 760 mm Hg. The outputs of each signal conditioner are recorded on separate, dedicated, on-board analog tape recorders.

Both reference and measured signals are conditioned for the 0-5 V input range of the onboard Soviet tape recorder. Electrical calibration values are 2 V for the high level and 0 V for the low level. These correspond to ideal physiological ranges of 0 to 200 mm Hg for pressure and a ±1 KHz frequency shift for Doppler flow. The flow output signal is conditioned for an idealized physiological range of -1 KHz to +4 KHz frequency shift. The semiconductor strain gauge pressure cells are excited by a 5 mA constant current source. The output is conditioned for an idealized -200 mm Hg to +300 mm Hg physiological pressure range.

Timer/Controller: Each data collection period is initiated by a ground-based start pulse through the Biosatellite data system. Upon receipt of this start pulse, the internal timer provided approximately twenty seconds each of high- and low-calibration signals followed by about 4.5 min of continuous, pulsatile data. At the end of the collection period, the controller disables power to the timer until receipt of the next start pulse.

Specifications

Dimensions:	160 x 160 x 150 mm
Weight:	4.5 kg
Power:	Lithium battery pack
Output Voltage:	0.0-5.0 volts (both units)
Range (ml/sec):	Velocity, 0.5-5.0; Pressure, 0.0-200
Accuracy:	Velocity, 1%; Pressure, 10%; Flow, 20% (est. of vessel diameter)
Artery Diameter:	2.0-5.0 mm (both units)

Data Acquisition

Cardiovascular data

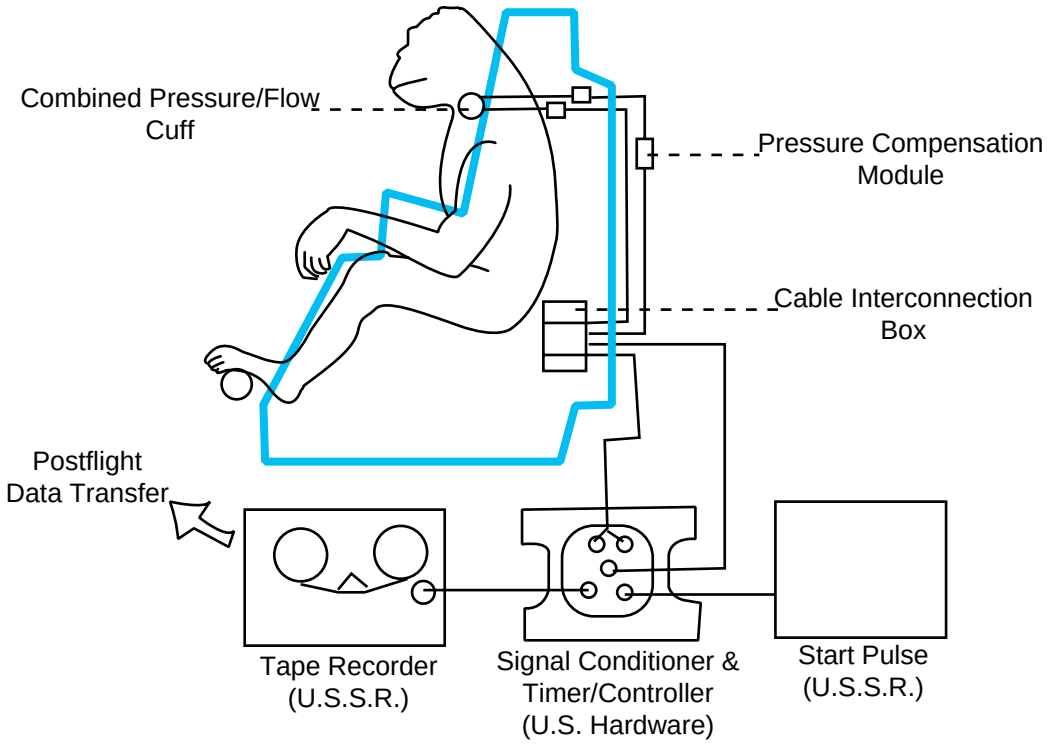
Related Ground-Based Hardware

Honeywell 15 channel FM tape recorder : Used to transfer data from Soviet tapes.

Analog-Digital Computer: Used for data analysis. Received data are digitized, stored and processed using a Digital Equipment Corporation PDP-11/34 computer with an AR-11 analog-to digital computer.

Publications

- Rasmussen, D.N. and R.C. Mains: U.S. Bioinstrumentation on Cosmos 1514. *Final Reports of U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514,* NASA TM-88223, 1986, pp. 37–70.
- Hines, J.W. and M.G. Skidmore: U.S. Bioinstrumentation Development. *Final Report of the U.S. Experiment Flown on the Soviet Biosatellite Cosmos 1667.* NASA TM-108803, May 1994, pp. 5–7.



Missions Flown Through 1990: **Cosmos 1514 (p. 145)**

Cardiovascular Experiment Hardware: Combined Pressure/Flow (CPF) Cuff

Hardware Description

The flow and pressure transducers are contained within a single cylindrical molded cuff that is placed around the carotid artery of the Rhesus monkey during surgical implantation. The leads pass under the skin and exteriorize at the monkey's lower back. The cuff is constructed of injection-molded plastic to ensure that surfaces are smooth and that the upper and lower sections mate closely. The cuff consists of two parts: the top portion of the assembly which contains both pressure and flow transducers, and the lower portion which consists of several interchangeable shells capable of fitting around vessels ranging from 2.5-5.0 mm in diameter.

Sensors:

Pressure is measured using a 4.5 mm diameter and 1.2 mm thick titanium disk transducer capable of chronic implantation within the body. Pressure is sensed by imbalance of solid state strain gauge elements cemented to the inner, unexposed surface of the transducer diaphragm in a wheatstone bridge configuration. To improve longevity of the preparation and minimize damage to the vessel, the pressure cell is placed on the vessel's external surface rather than intravascularly.

Flow is measured using Doppler ultrasonic crystals and the continuous wave technique. Crystals are positioned to lie on the leading edge of the cuff, proximal to the pressure transducer. The crystals are inserted at a compound angle, 45 degrees to the long axis of the vessel and 45 degrees towards its center. This placement of the crystals minimizes any turbulence effects from the decreased vessel cross section caused by the distally located pressure transducer.

Specifications

Dimensions:	Cuff is adjustable in size
Weight:	Unknown
Power:	5 mA constant current for pressure
Pressure Output Signal:	Conditioned to –200 mm Hg to 300 Hg over 0-5 V allowable range (for input to Soviet recorder)
Flow Output Signal:	Conditioned to –1 KHz to 4 KHz over 0-5 V allowable range

Data Acquisition

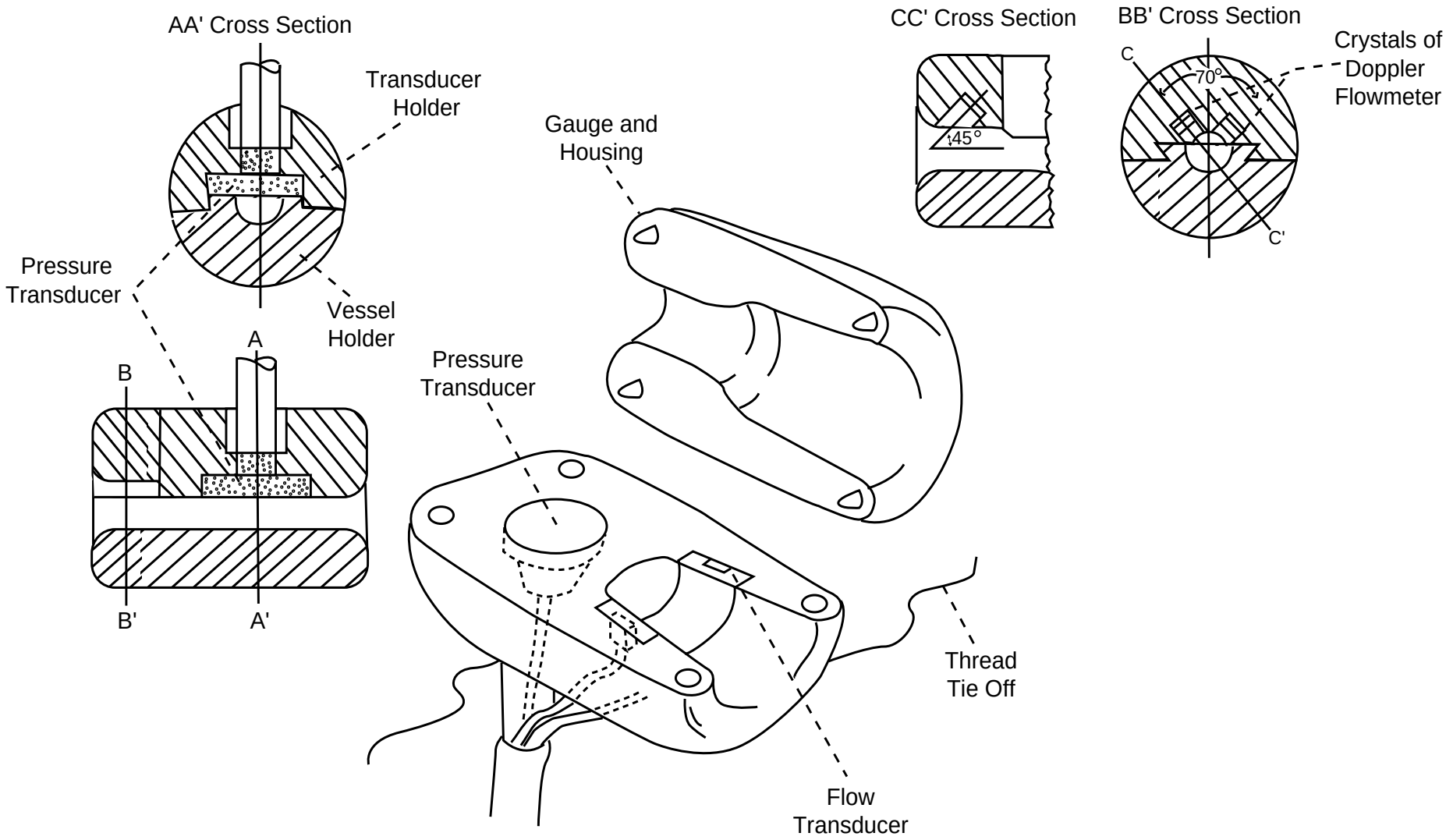
Blood pressure and blood flow

Related Ground-Based Hardware

Special Transducer Profile Test System: For characterizing performance preflight. System consists of a previously calibrated pressure transducer connected to 25 gauge needle, with an interface to the signal conditioner.

Publications

- Rasmussen, D.N. and R.C. Mains: U.S. Bioinstrumentation on Cosmos 1514. *Final Reports of U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514.* NASA TM-88223, 1986, pp. 37–70.
- Hines, J.W. and M.G. Skidmore: U.S. Bioinstrumentation Development. *Final Report of the U.S. Experiment Flown on the Soviet Biosatellite Cosmos 1667.* NASA TM-108803, May 1994, pp. 5–7.
- Hines, J.W. and M.G. Skidmore: In Vitro Characterization of Implantable Pressure Transducers. *Proceedings of the 39th Annual Conference on Engineering in Medicine and Biology,* Baltimore, Md., September 14–16, 1986.



Missions Flown Through 1990: **Cosmos 1514 (p. 145), Cosmos 1667 (p. 153)**

Hardware Description

Modifications to the Cardiovascular Experiment Hardware included the addition of an Ambient Pressure Sensor and a highly specialized data handling system (PC-DARS, see right), created to facilitate and allow for more accurate reporting of cardiovascular experiment data, following postflight transfer from the onboard Soviet tape recorder.

Combined Pressure/ Flow (CPF) Cuff*: Both flow and pressure transducers are contained within a single cylindrical molded cuff that is placed around the carotid artery of the Rhesus monkey. The leads pass under the skin and exteriorize at the monkey's lower back.

Signal Conditioners: Two cardiovascular signal conditioners are used: one measures pressure and flow from the CPF Cuff implanted in the primate; a second unit (along with the pressure compensation module) measures capsule ambient pressure to provide a correction and normalization for the implanted pressure sensor to 760 mm Hg. The outputs of each signal conditioner are recorded on separate, dedicated, on-board analog tape recorders.

Both reference and measured signals are conditioned for the 0-5 V input range of the onboard Soviet tape recorder. Electrical calibration values are 2 V for the high level and 0 V for the low level. These correspond to ideal physiological ranges of 0 to 200 mm Hg for pressure and a ±1 KHz frequency shift for Doppler flow. The flow output signal is conditioned for an idealized physiological range of -1 KHz to +4 KHz frequency shift. The semiconductor strain gauge pressure cells are excited by a 5 mA constant current source. The output is conditioned for an idealized -200 mm Hg to +300 mm Hg physiological pressure range.

Ambient Pressure Sensor: The Barocel pressure sensor is an addition to the experiment hardware, flown earlier on Cosmos 1514, that measures ambient pressure throughout the mission. This is important because the vascular pressure is referenced to ambient pressure which can change frequently within the spacecraft. Barometric pressure is measured to correct and normalize the implanted pressure sensor (see *Combined Pressure/Flow (CPF) Cuff*) to 790 mm Hg. No adjustments to the unit are possible. Power and signal conditioning are provided by an additional Signal Conditioner, with necessary modifications for processing ambient pressure data gathered on Cosmos 1667. Output of the sensor is adjusted for recording on the Soviet flight recorder. The 0.0 to 1,000 mm Hg range is equivalent to 0.0-5.0 V making output 0.5 V per 100 mm Hg. The device includes a highly accurate diaphragm capacitance transducer and is physically mounted in the spacecraft.

Timer/Controller: Each data collection period is initiated by a ground-based start pulse through the Biosatellite data system. Upon receipt of this start pulse, the internal timer provided approximately twenty seconds each of high- and low-calibration signals followed by about 4.5 min of continuous, pulsatile data. At the end of the collection period, the controller disables power to the timer until receipt of the next start pulse. For Cosmos 1667, the Timer/Controller was combined in a single unit with the Signal Conditioner for the Ambient Pressure Sensor.

Cardiovascular Experiment Hardware: Modification 1

Specifications

Dimensions:	160 x 160 x 150 mm (Sig. Con.)
Weight:	4.5 kg (Sig. Con.)
Power:	Lithium battery pack
Output Voltage:	0.0-5.0 volts
Range (ml/sec):	0.0-200 (ambient pressure)
Accuracy:	10% (ambient pressure)

Data Acquisition

Cardiovascular data and ambient pressure data

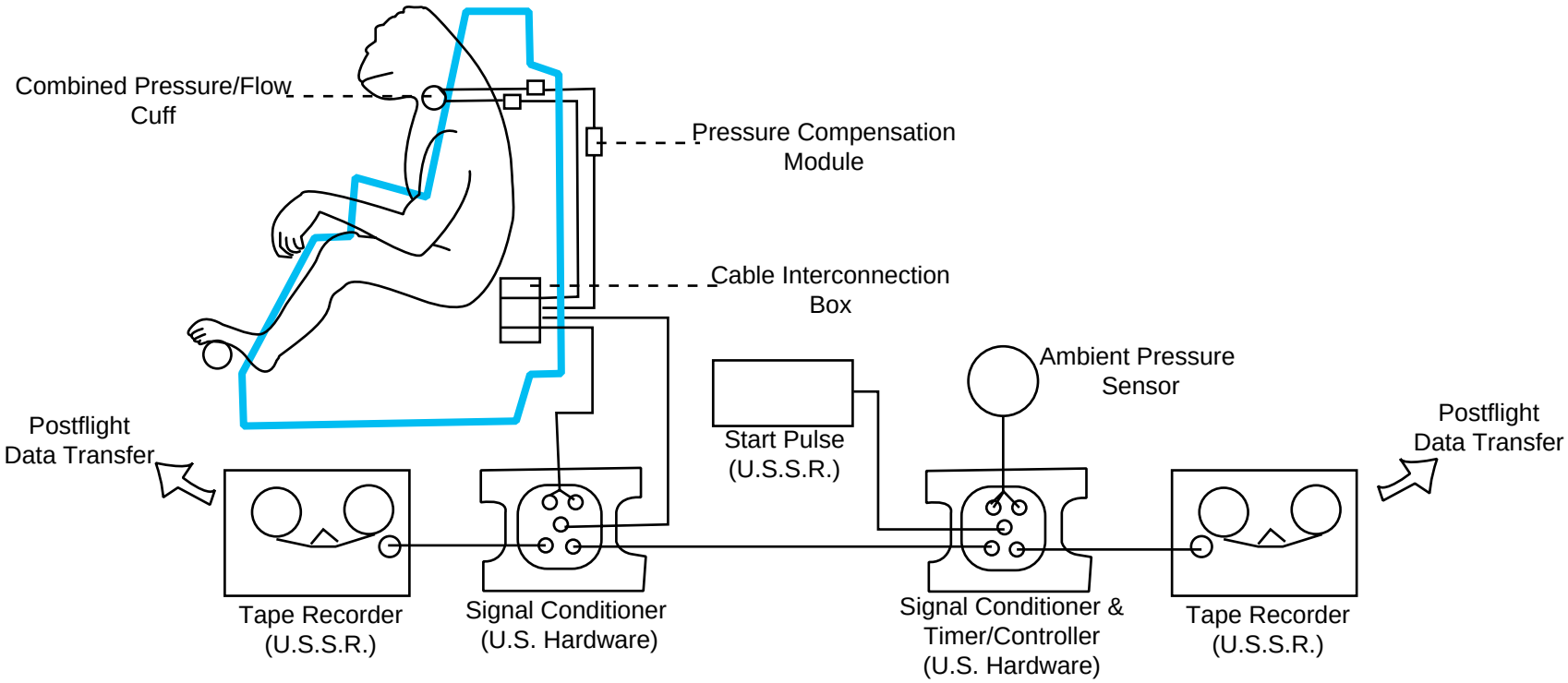
Related Ground-Based Hardware

Honeywell 15 channel FM tape recorder : Used to transfer data from Soviet tapes.

Personal Computer Data Acquisition and Reduction System (PC-DARS): An interactive data acquisition, display and analysis package intended for use on an IBM compatible system and a Data Translation 2801-A twelve bit analog-to-digital conversion board.

Publications

- Skidmore, M.G. *Cosmos '85: Cardiovascular Measurements Experiment Specifications and Procedures Manual.* NASA Ames Research Center, May 1985.
- Hines, J.W. and M.G. Skidmore: U.S. Bioinstrumentation Development. *Final Report of the U.S. Experiment Flown on the Soviet Biosatellite Cosmos 1667.* NASA TM-108803, May 1994, pp. 5–7.



Missions Flown Through 1990:Cosmos 1667 (p. 153)

Carrot Tissue Containers: Embryoid Container and Tumor Growth Containers

Hardware Description

Two types of containers for conducting carrot tissue studies onboard Cosmos biosatellites were developed. One is designed to support the germination of carrot embryoids and the other holds carrot disks for the study of tumor growth. The latter was maintained with and without onboard centrifugation on Cosmos 782 and slightly modified to hold more disks for Cosmos 1129.

Carrot Embryoid Container: This container was originally flown on Cosmos 782, and then again in a different configuration on Cosmos 1129. It consists of a group of plastic petri dishes, 50 mm in diameter, with clipped-on covers providing a hermetic seal. Nine of the dishes are stacked on a microsil "standoff;" a pyrel foam cushion (density number four) is placed in position; and the dishes are loaded into acrylic tubes, each about 6.5 cm in diameter and 10.5 cm in height. The "standoff" is four equally spaced legs extending from a circle, about 5 cm in diameter, all cut from a single piece of microsil. In loading the dish stack, the microsil circle is flattened against the top of the stack and the four legs are folded down the sides. The microsil cushions the stack against one canister end-cap (diameter 6.7 cm), while pyrel foam cushions and secures the stack against the other. To help ensure sterility, HEPA filters are placed in the end-caps, which each have a circle of twelve 0.6-cm-diameter holes for air entry. The containers are then inserted into a foam block. A small thermistor measures canister temperature. On Cosmos 782, some of the flight canisters were maintained on the onboard centrifuge; for Cosmos 1129, several radiation dosimeters were added to the flight configuration.

Carrot Tumor Growth Container I: This container was only flown on Cosmos 782 and consists of specially machined acrylic cylinders, 8.5 cm in diameter and 10.5 cm in height. Each cylinder contains a stack of three, closely fitting dishes, each 2.3 cm deep. A rimmed, 2.5 cm center hole penetrating each dish allows passage of a threaded metal rod that clamps together a complete canister of stacked dishes. Eight smaller holes (2 cm) in each dish provide seats to accommodate uniformly cut and sized, press-fitted disks of carrot tissue, for a total of twenty-four carrot slices per container. Anodized aluminum caps seal the stacks via the threaded metal rod. On Cosmos 782 one of the two flight units was maintained on an onboard centrifuge.

Carrot Tumor Growth Container II: This container was flown on Cosmos 1129 and consists of a series of plastic support plates or dishes which contain the carrot disks within a rectangular aluminum canister. Four dishes are stacked in each canister, and four carrot disks are placed in each dish (for a total of sixteen disks per canister). The plastic dishes are filled with a water agar solution to maintain high humidity and to seal the suspended carrot sections.

Specifications

Dimensions: 6.5 x 10.5 cm (Embryoid container)
Weight: Unknown
Power: None
Dimensions: 9.4 x 10.3 cm (Tumor I container)

Data Acquisition

Max/min temperature, radiation data (Cosmos 1129 only)

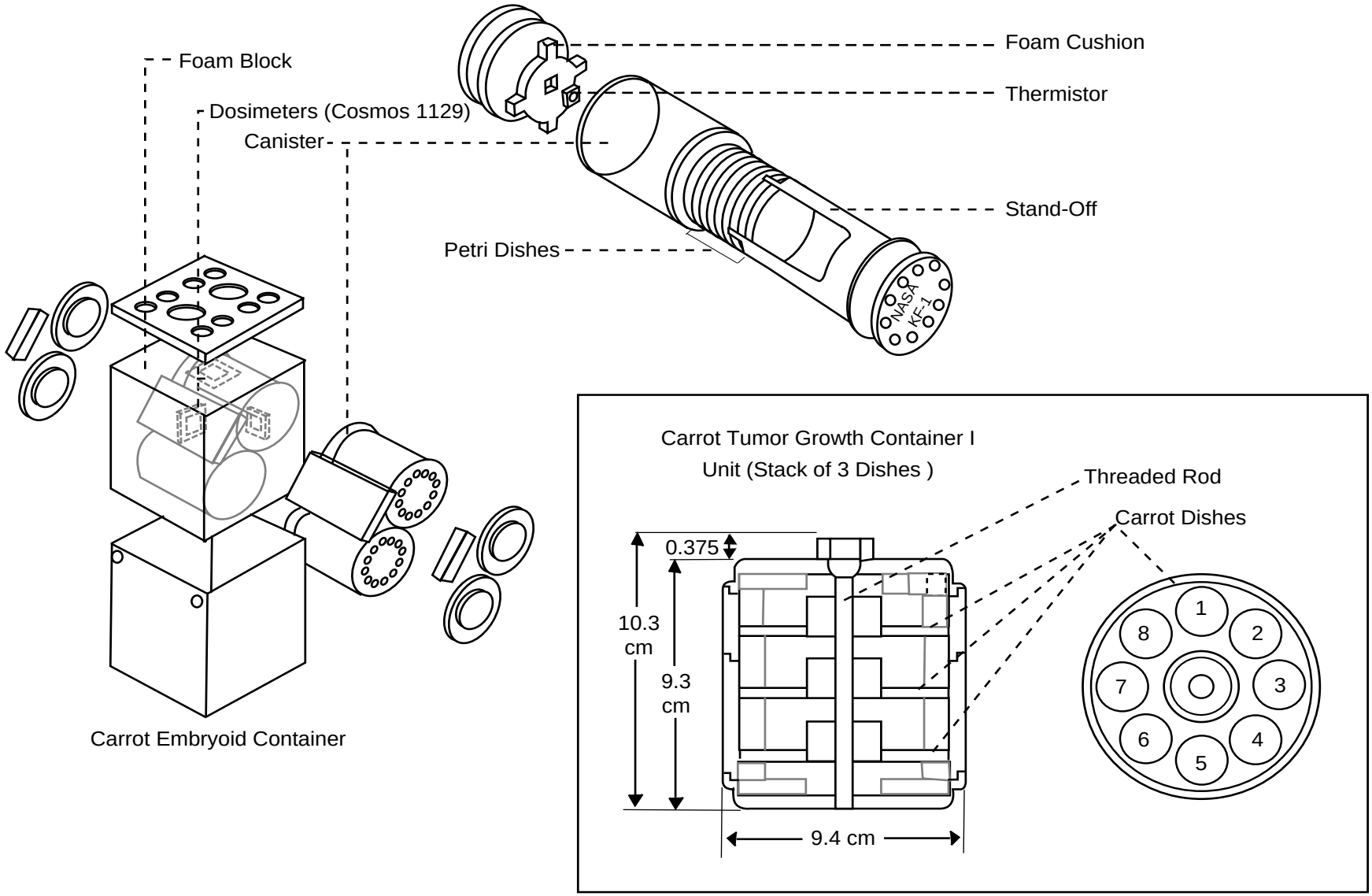
Related Ground-Based Hardware

None

Publications

- *Biolocheskiye Issledovaniya na Biosputnikakh 'Kosmos'* (Biological Studies on the Kosmos Biosatellites). E.A. Illyin and G.P. Parfenov, eds., Moscow, Nauka Publishing House, 1979.
- Krikorian, A.D., et al.: Growth and Development of Carrot Cells and Embryos in Space. *Final Reports of U.S. Plant and Radiation Dosimetry Experiments Flown on the Soviet Satellite Cosmos 1129.* NASA TM-81288, 1981, pp. 57–122.
- Steward, F.C. and A.D. Krikorian: The Morphogenetic Response of Cultured Totipotent Cells of Carrot at Zero Gravity. *Final Reports of U.S. Experiments Flown on the Soviet Satellite Cosmos 782.* NASA TM-78525, 1978, pp. 71-159.

Carrot Tissue Containers: Embryoid Container and Tumor Growth Containers



Missions Flown Through 1990:Cosmos 782 (p. 126), Cosmos 1129 (p. 139)

Hardware Description

The Circadian Periodicity Experiment (CPE) Package combines two life support systems developed separately to support either pocket mice or vinegar gnat (fruit fly) pupae in a spaceflight experiment. The specifications for the combined package were generated utilizing experience gained from design verification and laboratory evaluation models of the separate life support systems. The two flight hardware systems utilize a common Circadian Data System (CDS) and are packaged in the integrated CPE unit, which interfaces with the spacecraft for power, thermal control, and data retrieval and command functions. For Skylab-3, the CPE was mounted on Bay I of the Apollo Command Service Module. The entire CPE package is surrounded by a multi-layer of gold-coated mylar.

Pocket Mouse Experiment Hardware: Pocket mouse experiment hardware is capable of supporting six specimens and consists of a Cage Assembly, an Environmental Control System (ECS), Biotelemetry Implants, and the CDS.

Circadian Data System (CDS): The CPE data system consists of a data processor, memory, and power supply. The CDS scans all biological, environmental and engineering parameters for both experiments contained in the CPE. Collected data is stored in a core memory and transmits the data on command to ground receiving stations; data could also be telemetered real-time without any disruption of data storage. The CDS implements all commands and generates timing and control signals. CDS time coding is accomplished by 0 through 143 continuous sequential counts in 24 hours, and a memory write address data channel assures continuous operation of CDS data storage.

Vinegar Gnat (Fruit Fly) Enclosures: The vinegar gnat enclosures are sealed houses containing sufficient air to provide oxygen for the hatching flies and also adults during several days of continued hatchings. Four such enclosures were included in the CPE for flight on Skylab-3. The enclosure essentially consists of a pupa plate which could be warmed to induce pupa hatching, a temperature control for heating the plates, a programmable stimulus lamp operating on a delta ten-minute increment, and a photo detector for obtaining hatching counts. The addition of a simple low pass filter in the pupae counting circuitry reduces noise to an occasional ±2 counts. Parameters to be collected by the CDS for the Vinegar Gnat Enclosures (total of sixteen channels, four per enclosure) include lamp status, population count, and housing enclosure and pupa plate temperatures.

Fifteen pupae are placed in each of the twelve indentations for a total of 180, and the plate is mounted to the heating unit at the base of the housing. CO_2 generated by the pupa and flies is removed by reaction with a potassium hydroxide (KOH) solution in a small teflon cup attached to the pupa plate holder. The original solution placed in the cup is 10 g water and 1 g KOH, and should be expected to maintain a relative humidity of approximately 95%. The base of the enclosure is held at slightly lower temperature than the plate to provide a constant water vapor partial pressure of 0.21 psi and maintain a relative humidity of 100% at the coolest point of the enclosure surface and 62% at the surface of the pupa plate.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown

Data Acquisition

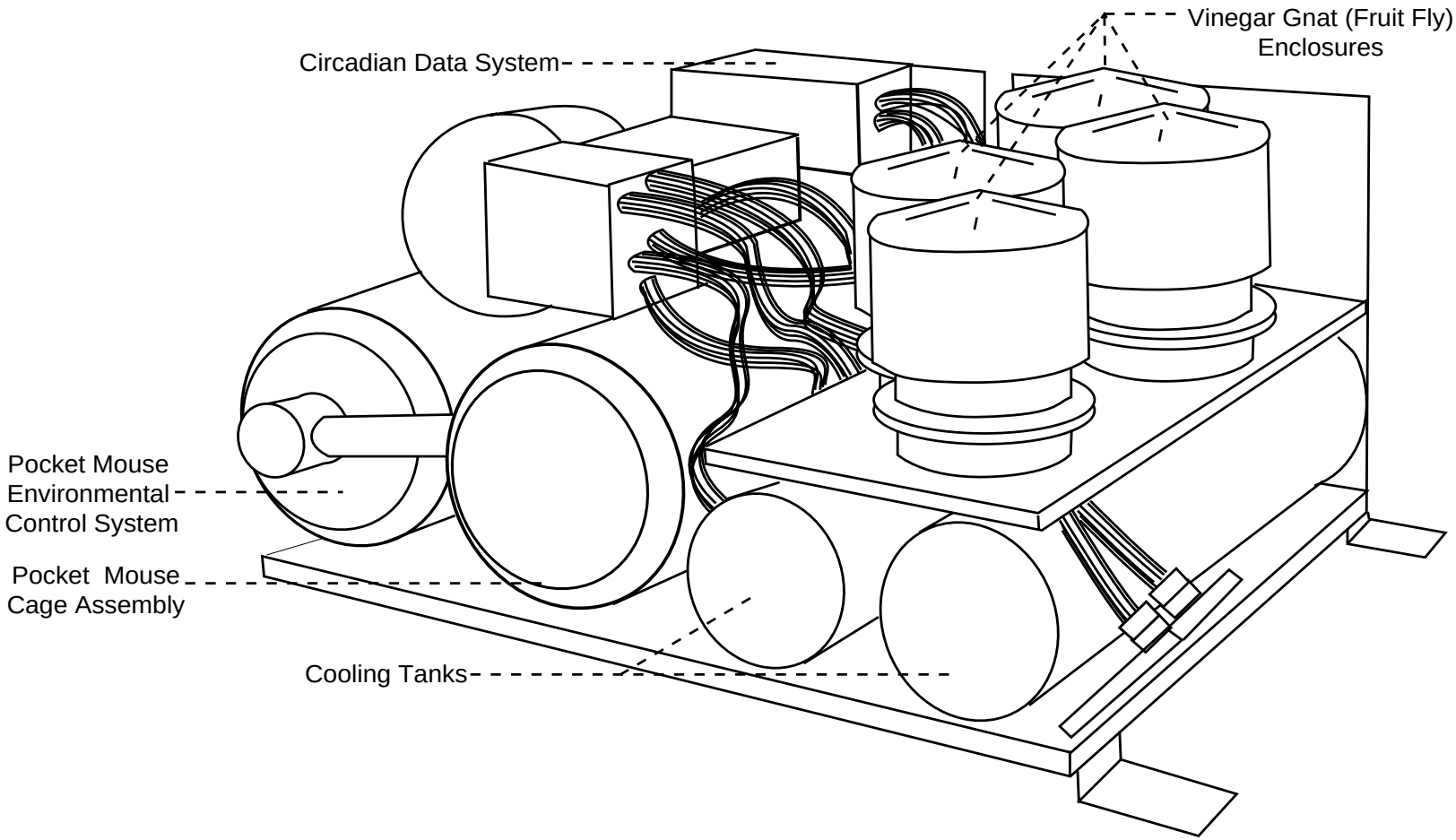
Body temperature, activity (Mice), hatching counts (Vinegar Gnat), and environmental data

Related Ground-Based Hardware

Control and Monitor Console: A ground unit to which the CPE could be mounted, providing power to the CPE and telemetry output. This is a large computer unit from which flight and backup CPEs could be simultaneously monitored for use in hardware verification and integration.
CPE Transporter: A wheeled cart to which the loaded CPE could be attached for transport to the launch site, equipped with a battery pack and monitoring device.

Publications

- Fairchild, M.K. and R.A. Hartmann. *Skylab S071/S072 Circadian Periodicity Experiment: Experimental Design and Checkout of Hardware.* Contract NAS2-6897 (NORT 73-320), November 1973.



Missions Flown Through 1990:Skylab 3 (p. 79)

Circadian Periodicity Experiment (CPE) Package: Pocket Mouse Experiment

Hardware Description

The CPE Pocket Mouse Experiment Hardware is capable of supporting six specimens and consists of a Cage Assembly, an Environmental Control System (ECS), Biotelemetry Implants, and a Circadian Data System (CDS) which is shared with the Vinegar Gnat (Fruit Fly) experiment. For the Pocket Mouse Experiment, one body temperature reading and one accumulated activity count for each animal is recorded every ten minutes for the duration of the experiment. Ambient air temperature for each cage is also monitored every ten minutes, and other engineering data are monitored once every forty minutes.

Cage Assembly: The cage assembly consists of a large circular tank containing six circular cages mounted on a common air distribution plenum, each with biotelemetry antennas and receivers. Each cage is 15 cm in diameter and 4 cm high and lined with porous polyethylene. Each cage is filled with 50 g of dried seeds and is capable of supporting one instrumented mouse. In the center of each cage is a 2.5 cm diameter fiberglass tube enclosing the receiving antennas and supporting the receiver; a circuit for scoring animal movement is an integral part of the receiver which provides both body temperature and animal activity data to the CDS. Conditioned air is supplied from the ECS to the plenum where it is distributed uniformly to each cage. Air is directed through each cage subplenum through the porous floor and ceiling of the cage at a rate of 85 liters/minute to the enclosed tank for return to the ECS. Ambient cage air temperature is monitored by a thermistor placed in the subplenum of each cage.

Environmental Control System (ECS): The ECS maintains an oxygen nitrogen atmosphere at 700 ± 15 mm Hg and 20 ± 10% relative humidity. It is a demand-type oxygen supply system in which the volume of absorbed CO_2 and water vapor are replaced from an oxygen reservoir. The circular ECS tank houses a fan, a charcoal-lithium hydroxide absorption canister, a dew point heat exchanger, a moisture separator, and a temperature control heater. Accessories mounted to the exterior of the ECS tank include: an oxygen supply bottle and pressure regulators; a coolant pump and control elements; and plumbing for connecting the heat exchanger to the spacecraft coldplate mount. Two supplemental cooling tanks are provided for intermittent use during periods when the spacecraft coldplate exceeded specified limits.

Biotelemetry Implants: Body temperature as a function of time is the primary data required from the mice, and a small block oscillator type transmitter was developed for the experiment. The pulse rate of the transmitter is determined by a variable resistor (thermistor) where resistance is proportional to temperature. The transmitter is powered by a 1.35 V nickel-cadmium battery, and the entire assembly is encapsulated in paraffin. Ready for insertion into the abdominal cavity of the mouse, the transmitter weighs approximately 1.3 g, measures 1.8 x 0.5 x 0.9 cm, and has an operating expectancy in the mouse of six to nine months. Animal activity is monitored by changes in signal strength; as the animal moves, the relationship between the transmitter and centrally receiving antenna also changes. A measure of relative animal activity is obtained by scoring the number of signal strength changes in each ten-minute period. When the animal is at rest, it is possible to monitor minor transmitter displacements, such as those reflecting animal breathing and heart rate. Considerable empirical experimentation is required to adjust the threshold of the detection circuit to score only physical displacement of the mouse.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown

Data Acquisition

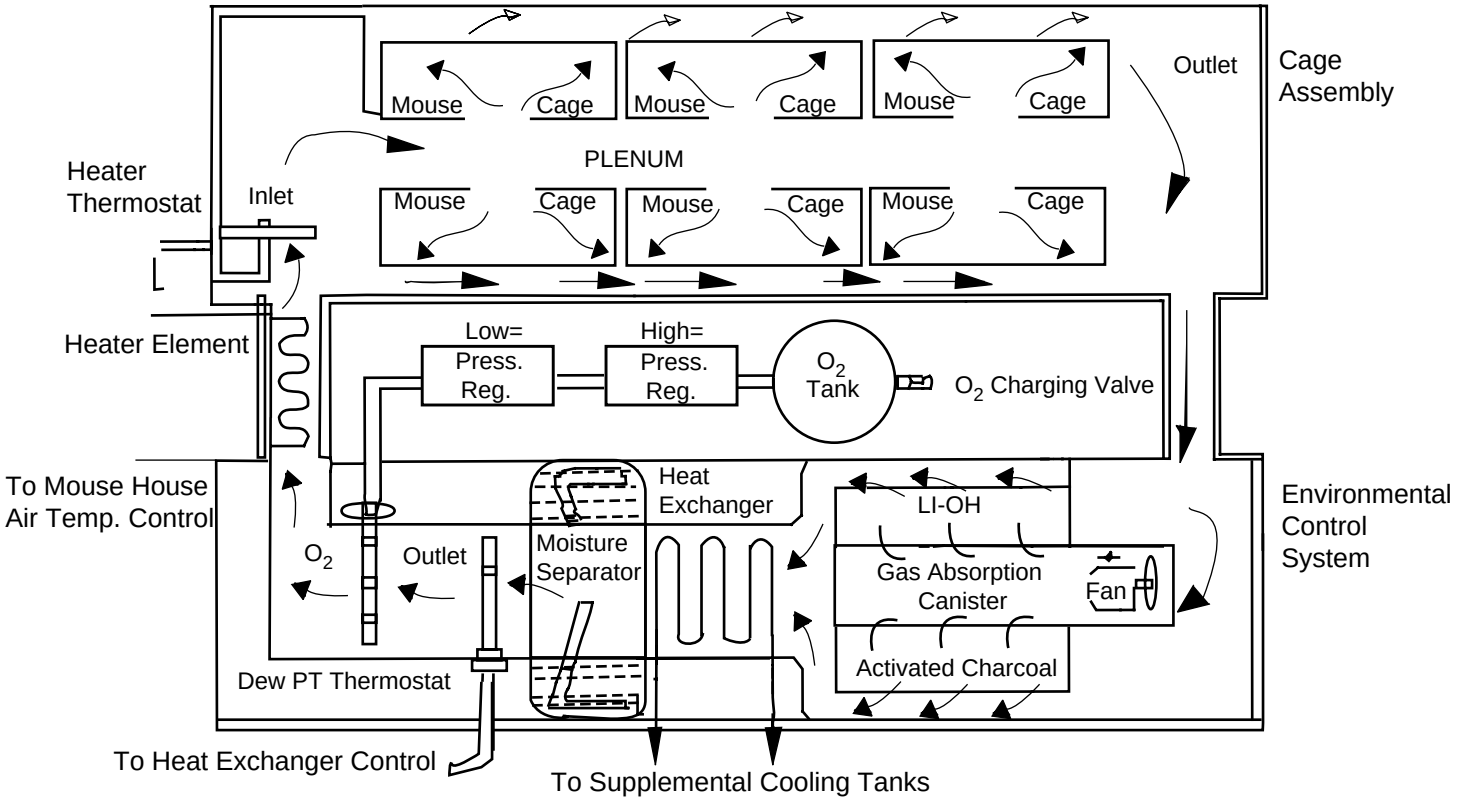
Body temperature, activity, and environmental data

Related Ground-Based Hardware

Animal Holding/Laboratory Monitoring Unit: Facility with same configuration as the CPE for obtaining baseline data from mice contained in simulated space hardware, holding mice at launch site, and a control environment apart from the flight backup unit.

Publications

- Lindberg, R.G. and P. Hayden. *Research on the Properties of Circadian Systems Amenable to Study in Space: Using Pocket Mice in Skylab Experiment S-071 for the Study of the Effects of Prolonged Weightlessness.* NASA CR-137523, June 1974.



Missions Flown Through 1990:Skylab 3 (p. 79)

Hardware Description

Three sensors (U.S. or Soviet) are used to measure skin temperature, body temperature, and motor activity. These data are recorded on a U.S.-developed Solicorder Flight Package.

Sensors:
Body temperature is obtained from a subcutaneous sensor developed by the Soviet research team for implantation in the axilla of the monkey. It transmits a radio signal to a Soviet receiver which provides a pulse train whose frequency is proportional to temperature (Soviet-provided table for °C/Hz). An event-counting Solicorder unit is used to count the pulses and store a frequency in memory for later conversion to temperature data. The recorder is modified for compatibility with the Soviet receiver signal characteristics. Electrical isolation from the Soviet receiver is achieved with an optical coupling to avoid ground-loop problems.

Skin temperature is measured by a U.S.-developed thermistor attached to the monkey's ankle skin by cyanoacrylate glue, and then covered with soft, foam tape. The output of the thermistor is recorded on a dedicated temperature-reading Solicorder unit.

Activity is monitored using a U.S.-developed sensor attached to the monkey's restraint jacket and signal conditioner. The activity sensing system required extensive testing with monkey subjects to determine the proper sensitivity setting and sensor location. The output of the sensor is filtered and amplified, fed into its dedicated event-counter Solicorder unit and totaled over sixteen-minute intervals.

Solicorder Flight Package: The Solicorder is a solid state, single-channel, digital recorder available either in temperature-reading or event-counting models. Three Solicorder units were included in the flight package for Cosmos 1514. Two event counter-type and one temperature-type recorders are combined into a single package for flight. The flight package uses only the commercial circuit boards which were custom-manufactured to NASA standards. Power is supplied by lithium batteries.

Temperature Recording System: To record ambient temperature inside the biosatellite, a U.S.- developed temperature recorder was planned for the flight. Although an earlier version of the unit was successfully flown on Cosmos 1129, a last-minute requirement to test the function of the recorder at the launch site could not be fulfilled. As a result the unit was not flown on Cosmos 1514.

Specifications

Dimensions:	150 x 55 x 190 mm (Solicorder)
Weight:	2 kg
Power:	Lithium battery pack
Frequency:	1 sample/16 minutes
Range:	0-3584 events (activity)
Range:	23-39 °C (skin temp.)
Range:	0-2000 Hz (body temp., converted to °C using Soviet-provided table)

Data Acquisition

Skin and body temperature, activity

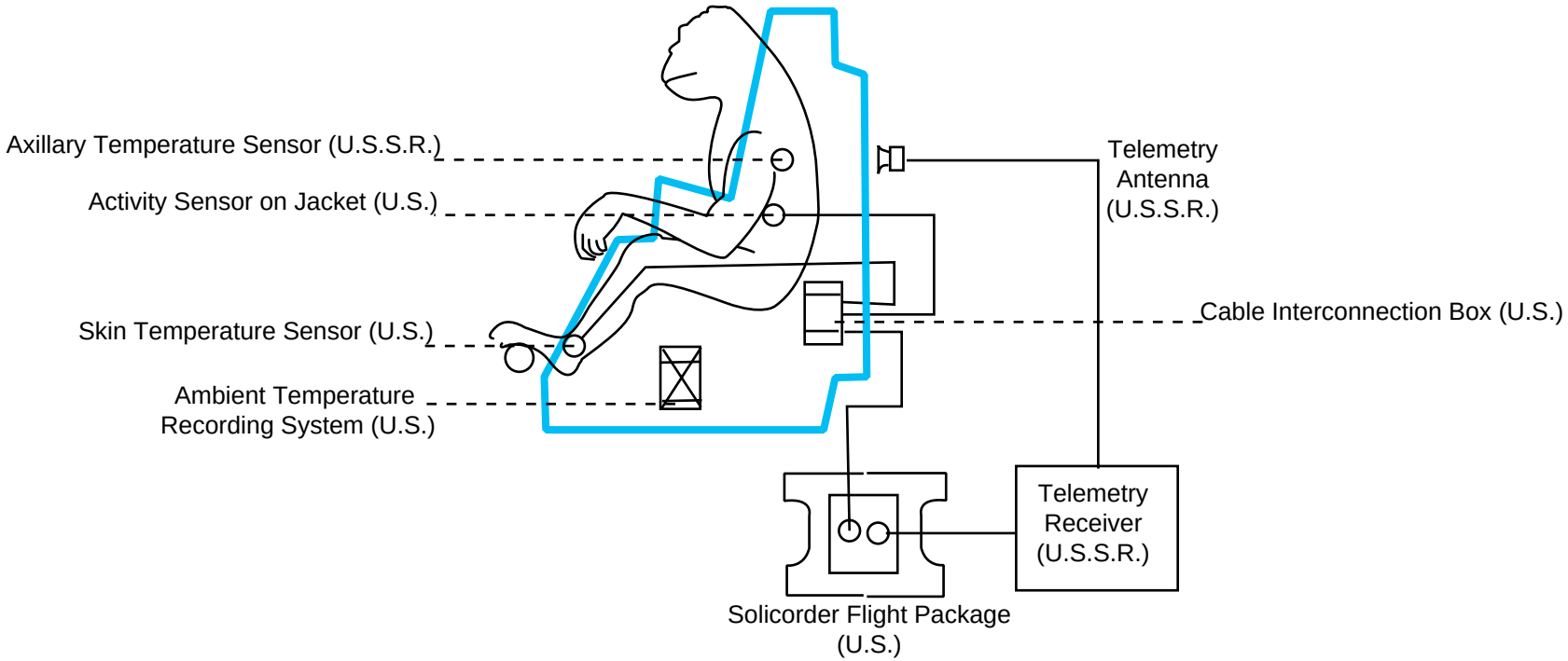
Related Ground-Based Hardware

Data Readout and Control Unit (DRCU): This commercial Solicorder unit is used to start the flight Solicorders at the beginning of an experiment and to readout the stored values in degrees centigrade.

Apple II Computer: Developed as a backup for the DRCU.

Publications

- Rasmussen, D.N. and R.C. Mains: U.S. Bioinstrumentation on Cosmos 1514. *Final Reports of U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514.* NASA TM-88223, 1986, pp. 37–70.



Missions Flown Through 1990:Cosmos 1514 (p. 145)

Circadian Rhythm/Temperature (CR/T) Experiment Hardware: Modification 1

Hardware Description

The hardware for this experiment monitors eight different parameters, including animal motor activity, skin temperature (ankle, thigh, and head), ambient temperature near head and ankle, heart rate, and axillary temperature. Hardware includes a variety of sensors and the Circadian Rhythm/Temperature-Signal Processor (CR/T-SP), which records all parameters required for the U.S. investigation.

Sensors:

Motor Activity is monitored using U.S.-provided piezoelectric sensors secured to the restraint harness over the monkey's chest.

Skin Temperature is measured by U.S.-provided thermistors directly attached to the monkey at three different locations. The head skin thermistor is attached to the temple of the animals. The thigh and ankle skin thermistors are attached to the animal's skin in these locations. To securely attach them and provide strain relief, skin temperature sensors are taped in place and glued with cyano-acrylate adhesive.

Ambient Temperature is monitored by two U.S.-provided thermistors attached to the top and bottom of the monkey chair.

Heart Rate is derived from a Soviet-supplied ECG sensors attached to the monkey. The ECG sensors are hard-wired to the Soviet recording system, and transmit pulses corresponding to R-waves, which are sensed and converted to heart rate within the CR/T-SP.

Axillary Temperature is measured by a Soviet-supplied biotelemetry sensor implanted in the axilla of each animal. The temperature is supplied to the CR/T-SP via a Soviet telemetry receiver as a pulse-train varying in frequency with changes in body temperature.

Circadian Rhythm/Temperature-Signal Processor (CR/T-SP): The CR/T-SP is a self-contained signal processing and digital data storage device. It consists of circuitry which conditions incoming physiological signals for data processing and a microprocessor-controlled digital data recorder which stores data for later recovery by a ground-based computer. For Cosmos 2044, data were collected at five-minute intervals. The flight unit is powered by a removable lithium battery power pack which holds sixteen non-rechargeable lithium batteries. A CR/T-SP interface box provides an interconnection point between the CR/T-SP and the sensors.

Specifications

Dimensions: approx. 15 x 10 x 10 cm (CR/T-SP)
Weight: approx. 5 lbs. (CR/T-SP)
Power: Lithium battery pack
Sample Rate: 5 minute intervals

Data Acquisition

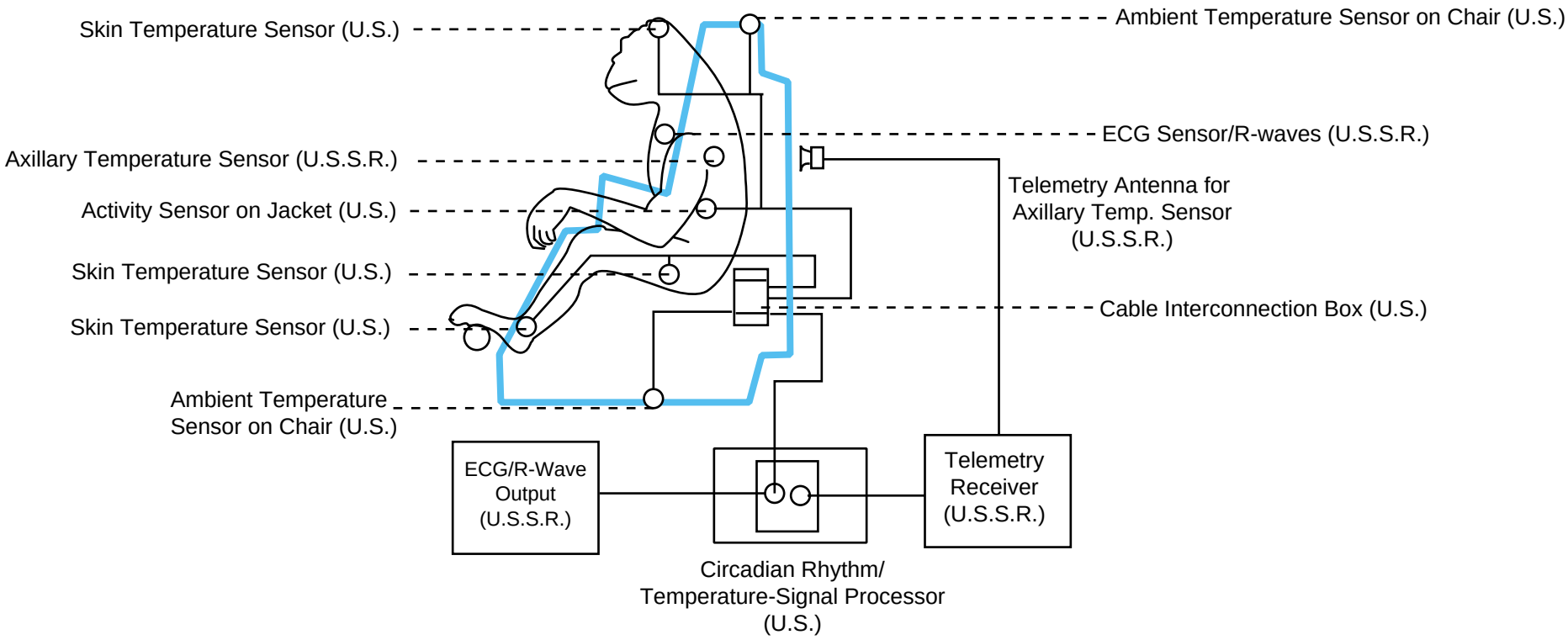
Motor activity, skin and ambient temperature data, and physiological parameters

Related Ground-Based Hardware

Ground Readout Unit: A ground readout unit is used to test the operation of the CR/T-SP, to begin data sampling and to recover data stored in the CR/T-SP. These functions are adequately served by the use of an IBM PC.

Publications

- Skidmore, M.G. and J. Connolly: U.S. Flight and Ground Support Hardware-B. Experiment Specific Hardware. *Cosmos 2044 Biosatellite Mission Description and U.S. Final Reports of Monkey and Rat Experiments.* NASA TM 108802, September, 1994.



Missions Flown Through 1990: **Cosmos 2044 (p. 150)**

Drosophila (Fruit Fly) Experiment Package

Hardware Description

The Drosophila (fruit fly) Experiment Package consists of eight insect modules assembled into a two-tiered container. Prior to flight, each module base is filled with melted culture medium and a retaining sieve inserted. Once filled, the Drosophilids are added and the cover is affixed. Preflight testing showed that 75 inseminated females could be loaded into a single module with good survival. Each of the eight modules is inserted into the housing frame, which is built as a spherical segment so that all modules in each frame are equidistant from the radiation source. Modules are mounted in two horizontal rows of four each, and brackets are placed over the modules using nylon screws. The larvae package is installed behind the adult, for a total of sixteen modules; it has a greater radius of curvature and receives a lower intensity of radiation. The container holds a thermistor for recording temperature and small square holders for the radiation detectors.

Radiation Dosimeters: LiF radiation dosimeters are attached to each of two container units to measure dose received at two sites: 1) the fore compartment where it is exposed to an estimated dose of 1,200 to 1,500 r from an onboard ^{85}Sr source and 2) the aft compartment where the unit is receives lower radiation doses due to curvature differences.

Specifications

Dimensions: 2.5 cm^2 (each module)
Weight: Unknown
Power: None

Data Acquisition

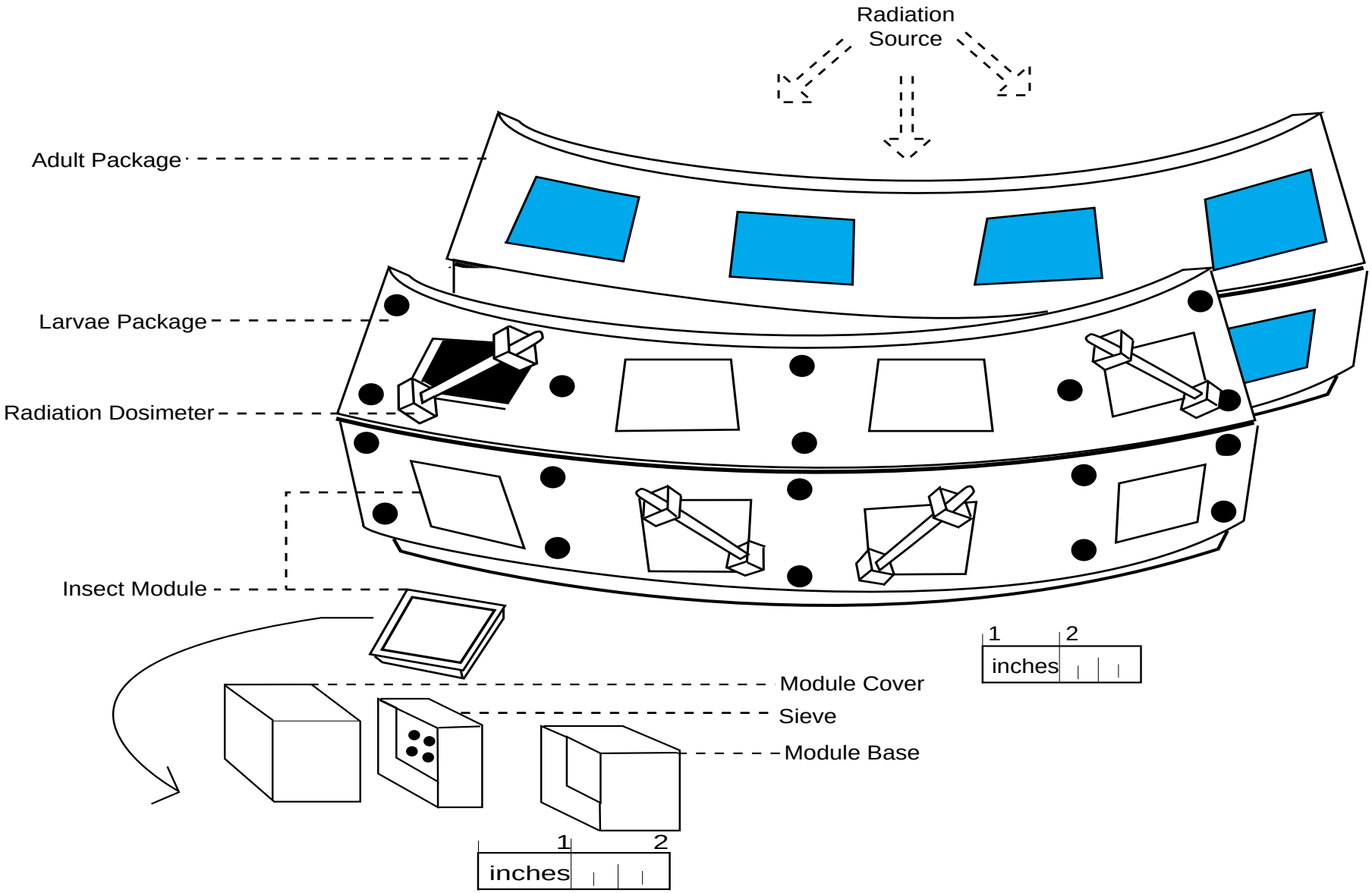
Radiation and temperature data

Related Ground-Based Hardware

None

Publications

- Browning, L.S.: Effects of the Space Environment on Radiation-Induced Damage in the Reproductive Cells and Pupae of Adult Drosophila. *Bioscience.* Vol. 18 (No. 106): 570-582, December 1969.
- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.



Missions Flown Through 1990: **Biosatellite I/II (p. 44)**

Dynamic Environment Measuring System (DEMS)

Hardware Description

The Dynamic Environment Measuring System (DEMS) is an instrumentation package that monitors and records Spacelab vibration, acoustic, and acceleration levels during launch and re-entry. Data are used to monitor the stimuli various biological systems experience under launch and reentry loads. A microphone, a triaxial-vibration sensor unit, and a triaxial-accelerometer unit function, respectively, as the acoustic, vibration, and acceleration transducers. One other device, the DEMS MET (Mission Elapsed Time) Slow Code Generator, converts the orbiter's pulse width modulated time code (100 Hz) to an amplitude modulated "slow code" (10 Hz) which is recorded by the DEMS tape recorder. The DEMS Signal Conditioner passes only certain frequency ranges from the sensors to the recorder. The axes and frequency range of the various signals are as follows:

Acceleration: X, Y and Z axes, low frequency only (DC-20 Hz) for three unique signals.
Vibration: X, Y and Z axes, low and high frenquencies (20-160 Hz, 50-2,000 Hz) for six unique signals.
Acoustics: low and high frequencies (20-160 Hz, 50-6,000 Hz) for two unique signals.
MET Slow Code: low frequency (10 Hz) for one unique signal.

During launch and re-entry, the DEMS cassette recorder collects the signals on two cassette tapes, seven tracks per tape (the eighth channel on each tape is not used). The twelve DEMS signals are distributed on the two cassette tapes within the DEMS; X-acceleration and MET signals are recorded on both tapes to help synchronize the two separate groups of data. The DEMS is designed to activate automatically at launch and re-entry, but can also be manually controlled. Once activated, the DEMS records data automatically for ninety minutes.

For SL-3, the DEMS was located in the Spacelab adjacent to the RAHF and measured three-axis vibration, three-axis acceleration, and acoustic noise levels. The unit was turned on by manual switch activation by the crew in the aft-flight deck prior to launch. Recorded tapes of the ascent were removed by the crew during orbit and exchanged with new tapes to record conditions associated with re-entry and landing. For data reduction, digital information on the tapes was decoded using a special cassette playback unit. The output of the cassette unit was fed, one cassette at a time, into a 14-track recorder. Along with the MET pulses, the most apparent and readable signals were acceleration values with repect to the gravity vector: the X-acceleration at launch (Shuttle length) and the Z-acceleration at descent (Shuttle height). DEMS information was correlated with reactions of the animals and performance of the hardware.

Specifications

Dimensions:	36.5 x 44.2 x 15.9 cm
Weight:	15 kg (33 lb)
Power:	8.5 W
Channels:	8 channels per tape
Frequency Ranges:	see description

Data Acquisition

Acceleration, acoustic, and vibration data

Related Ground-Based Hardware

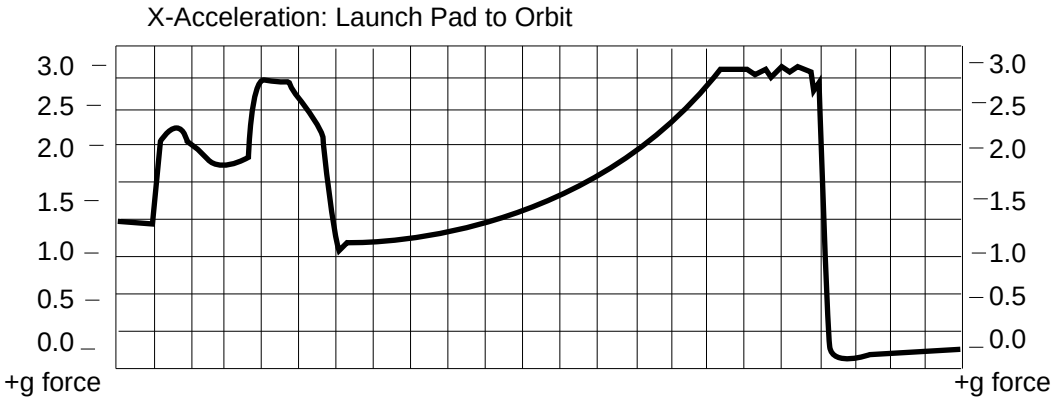
Test Equipment: To test and verifiy DEMS operation before loading in the Spacelab.

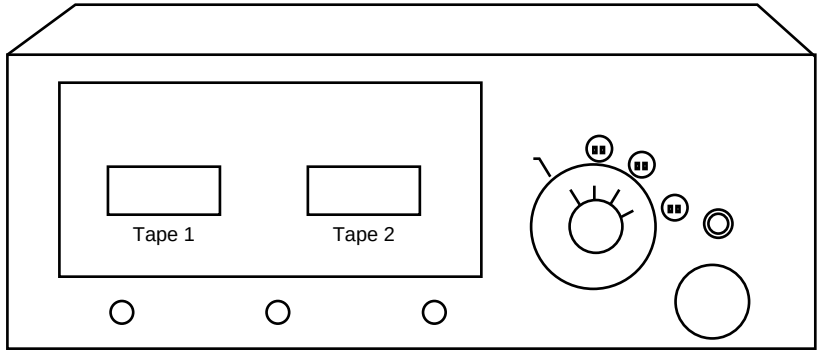
Cassette Playback Unit: To decode digital information from DEMS cassette tapes during playback.

14-Track Recorder: To support data reduction and synchronization of recorded DEMS signals.

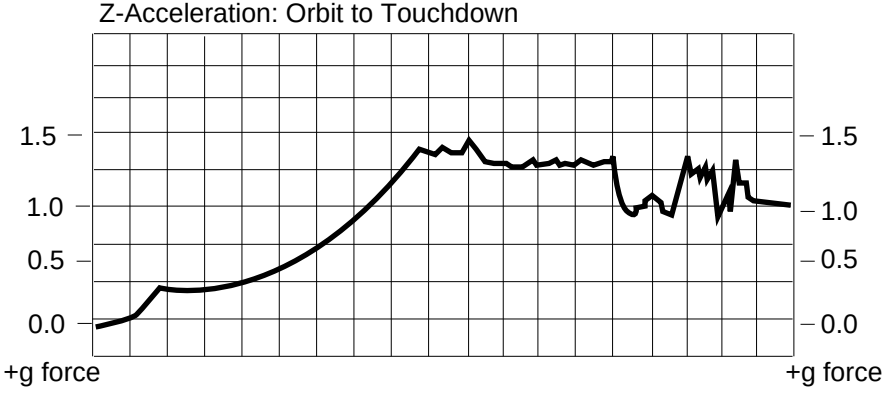
Publications

- *Spacelab-3, 60 Day Report*. NASA-Ames Research Center: Space Life Sciences Payload Office, April 1985.
- *Life Sciences Laboratory Equipment Catalog*. NASA-Ames Research Center: Space Life Sciences Payloads Office, May 1989, pg. 8.





DEMS Recorder



Missions Flown Through 1990: **STS51B/SL-3 (p. 85)**

Hardware Description

The Frog Otolith Experiment Package (FOEP) contains all apparatus necessary to assure survival of two frogs. Specimens are housed in a water-filled, self-contained centrifuge which supplies the test acceleration during orbit. Frogs are demotorized to prevent dislodging of implanted electrodes and to reduce their metabolic rate. The FOEP was designed for flight as part of the Apollo Applications Program; however, the package is equipped for flight on an unmanned spacecraft.

Life Support System (LSS)* The LSS maintains a regulated environment within the FOEP to assure the survival and normal functioning of two demotorized frogs. The lower bulkhead of the inner assembly structure provides mounting space for all life support equipment.

Canister: The outer housing of the FOEP is a pressure-tight canister 18.063 inches in diameter and 18.5 inches long. The bottom closure and removable top lid are both slightly domed to prevent implosion should pressure reversals be encountered. The inner assembly structure is fastened to a support ring approximately 6 inches from the bottom of the canister and consists of upper and lower bulkheads joined by a cylinder. Cutouts in the cylinder permit access to the centrifuge, which houses the frogs. Near the top of the canister are two electrical feed-through receptacles for the power supply and data line.

Centrifuge: The centrifuge is a hollow cylinder 6 inches in diameter and 13.5 inches long with both end caps in place. The cylinder is mounted perpendicular to the canister and supported by ball bearings housed in the upper and lower bulkheads. The rotational axis of the centrifuge is formed by shafts centrally located in the vertical plane at right angles to the cylinder, held in place by the ball bearings. Thin, shallow-domed end caps are bolted to each end of the centrifuge with intervening rubber gaskets to prevent leakage. In the center of each cap is a fitting which allows frog specimens to be fully instrumented and mounted directly to the end caps before insertion into the centrifuge, and immersion. The water serves as a cushion for the high accelerations and vibrations of launch and as a medium for gas exchange via the frogs' skin. The centrifuge is locked in position and not released until after the spacecraft orbit is fully stabilized. The motor which drives the centrifuge is mounted to the upper bulkhead. Signal amplifiers and an accelerometer are mounted on the centrifuge.

Neutral-Buoyancy Electrode: The micro-electrode consists of a probe of tungsten wire 50 µm in diameter, sharpened electrically to a point less than 1 µm in diameter and completely insulated to the tip. A bubble of air trapped in the polyethylene tubing which contains the probe adds buoyancy and makes the electrode the same density as the nerve in which it is implanted, thereby allowing the two to move together. A section of paraffin is used to connect the electrode to a handle which is used only during the implantation process, then removed. Nerve impulses detected by the microelectrodes are fed into a preamplifier directly attached to the frog's jaw, and passed on to a post-data amplifier for spacecraft telemetry.

Specifications

Dimensions: 18 in diameter x 18 in length
Weight: 91 lbs (loaded)
Power: Unknown

Data Acquisition

ECG, body temperature, and vestibular activity

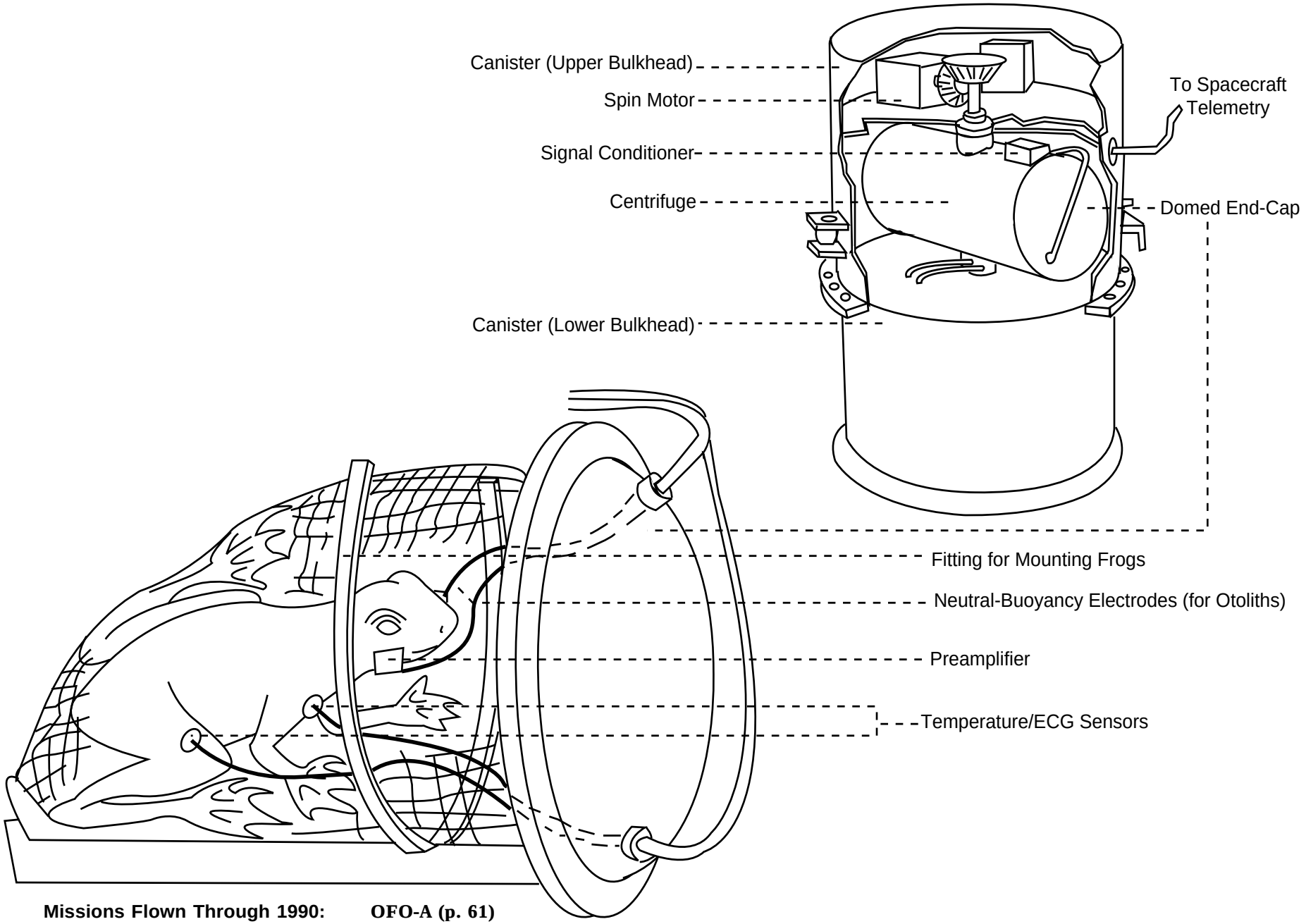
Related Ground-Based Hardware

FOEP Test Unit: Ground unit to which the FOEP could be connected preflight for ventilation and verification of environmental conditions prior to loading in the spacecraft.

Publications

- Gualtierotti, T. et al. *Orbiting Frog Otolith Experiment: Final Report.* Contract NASW-2211 (N72-30055), January 1972, 353 pages.
- anonymous. *Orbiting Frog Otolith Satellite Mission Performance Report.* Contract NAS6-1637 (No. 1333-032), December 1970.

Frog Otolith Experiment Package (FOEP)



Missions Flown Through 1990: **OFO-A (p. 61)**

Frog Otolith Experiment Package (FOEP): Life Support System (LSS)

Hardware Description

The FOEP Life Support System (LSS) maintains a regulated environment within the FOEP to assure the survival and normal functioning of the experimental specimens. The LSS is designed to meet the physiological requirements of two demotorized frogs weighing 350 g (0.7 lb) each. Frogs are demotorized by cutting the limb nerves, which reduces their metabolic rate. In this condition, the frogs require no artificial respiration and can remain healthy without being fed, for as long as a month. After being installed in the centrifuge the frogs are completely immersed in water, which serves as the medium for exchange of oxygen and carbone dioxide and heat through the frog's skin.

The LSS primarily consists of two closed loops: one containing liquid and the other containing gas. The lower bulkhead of the inner assembly structure provides mounting space for all LSS equipment. The oxygen supply system operates through these loops and includes a 4.5 cm^3 capacity oxygen bottle, a pressure reducer and regulator, an artificial lung, CO_2 absorber, and water supply. Limited control over the temperature of the frogs' environment is available by means of a water evaporator/heater.

Artificial Lung: The interface between loops occurs at a selectively permeable membrane of silicon rubber which separates the liquid and gas. This membrane, called the lung, passes oxygen from the gas loop to the liquid loop, and CO_2 from the liquid loop to the gas loop.

Liquid Loop: The frogs, housed in the centrifuge, are in the liquid loop. Moving from the lung to the frogs, the loop contains water and dissolved oxygen; moving from the frogs back to the lung, it contains water and free CO_2. A double layer of polyurethane foam lining the interior of the centrifuge prevents frog waste matter from fouling the water circulation system. Water is circulated through the liquid loop using a small pump and must pass through the filter before leaving the centrifuge.

Gas Loop: The gas loop consists of a circuit in the lower bulkhead through which oxygen is circulated by a small pump. The pump delivers pure oxygen to the lung where some of it passes into the liquid loop, while the remainder becomes mixed with the CO_2 coming from the liquid loop. From the lung, the oxygen-CO_2 mixture is passed through a bed of Baralyme which absorbs the CO_2. Pure oxygen is returned from the Baralyme to the pump and recirculated. The oxygen supply is replenished by gas from the small oxygen tank.

Evaporator/Heater: Augmented by the thermal environment of the spacecraft, the water evaporator and 8 Watt electric heater will maintain water temperature at 60 ± 5 °F. The water supply for the evaporator is contained in a rubber bladder supported by a ring in the canister immediately above the lower dome. When water temperature exceeds the nominal 60 °F, a ground command actuates a timing circuit operating a valve. As a result of the ambient pressure inside the canister, water is forced from the bladder through the valve and into the evaporator. Internal heat loads are transferred through a head exchanger to the evaporator and are dissipated in evaporating the water.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown

Data Acquisition

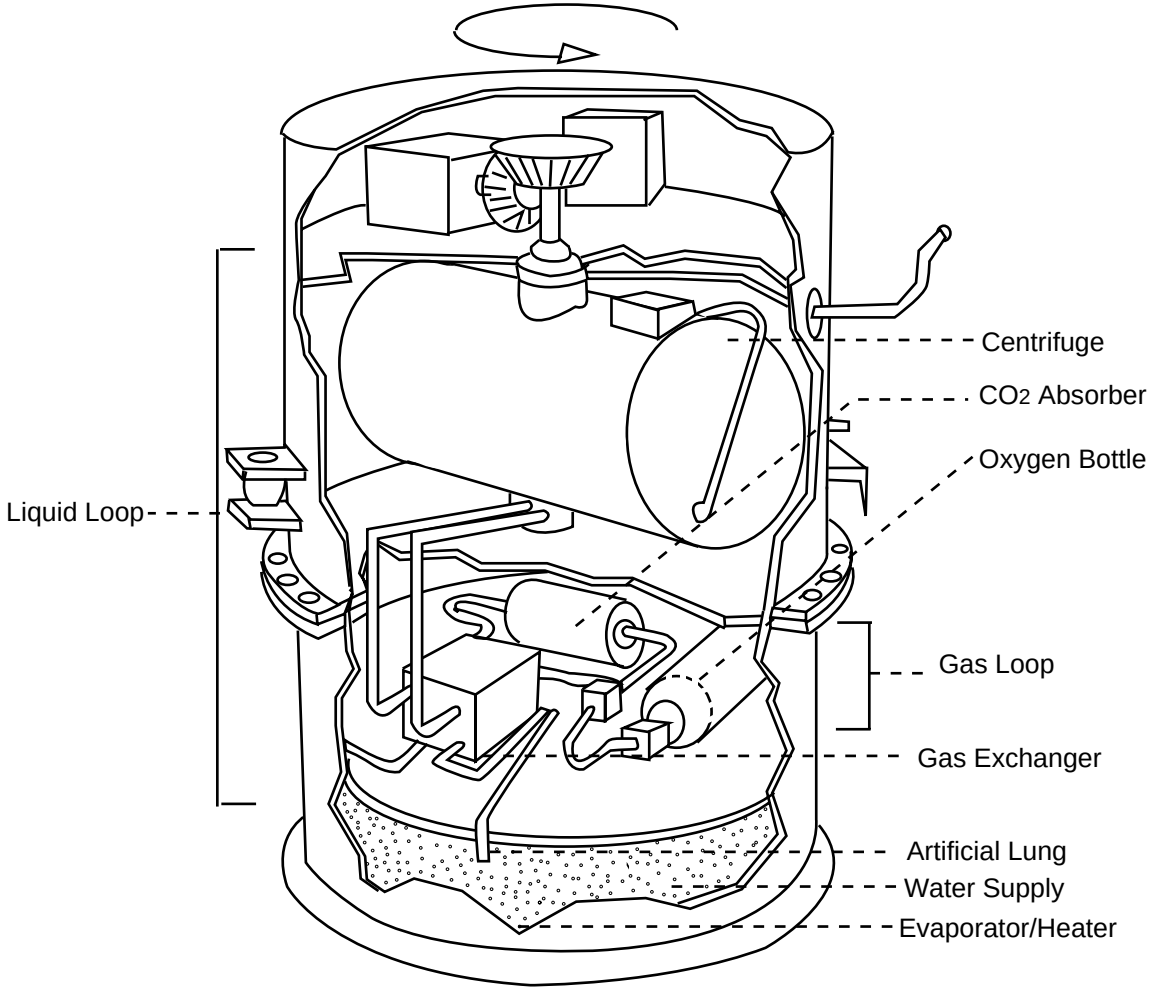
Environmental parameters

Related Ground-Based Hardware

FOEP Test Unit: Ground unit to which the FOEP could be connected preflight for ventilation and verification of environmental conditions prior to loading in the spacecraft.

Publications

- Gualtierotti, T. et al. *Orbiting Frog Otolith Experiment: Final Report.* Contract NASW-2211 (N72-30055), January 1972, 353 pages.
- anonymous. *Orbiting Frog Otolith Satellite Mission Performance Report.* Contract NAS6-1637 (No. 1333-032), December 1970.



Missions Flown Through 1990: **OFO-A (p. 61)**

Habrobracon (Wasp) Experiment Package

Hardware Description

The Habrobracon (wasp) Experiment Package consists of four modules which are screwed on the part of the package facing the radiation source. There is a central depression in each module where the wasp is placed. A screen is fitted over the wasp and capped. A thermistor to record the local temperature is located centrally between the modules. Five packages were flown; four exposed to varying doses of radiation from the ^{85}Sr source, and one placed in the shielded portion of the spacecraft. A secondary equilibrium shield is set in place in front of the package to minimize absorption and scattering of the gamma rays from the on-board radiation source. The package placed closest to the radiation source has a concave face for placement of the wasp modules to ensure adherence to the isodose requirements. The package placed in the shielded portion of the spacecraft holds more modules so that more wasps could be contained, some of which were irradiated before flight.

Radiation Dosimeters: Each module carries three Toshiba glass rod dosimeters. Additional dosimetry can be measured by LiF powder in tubes held in front of and behind the modules.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: None

Data Acquisition

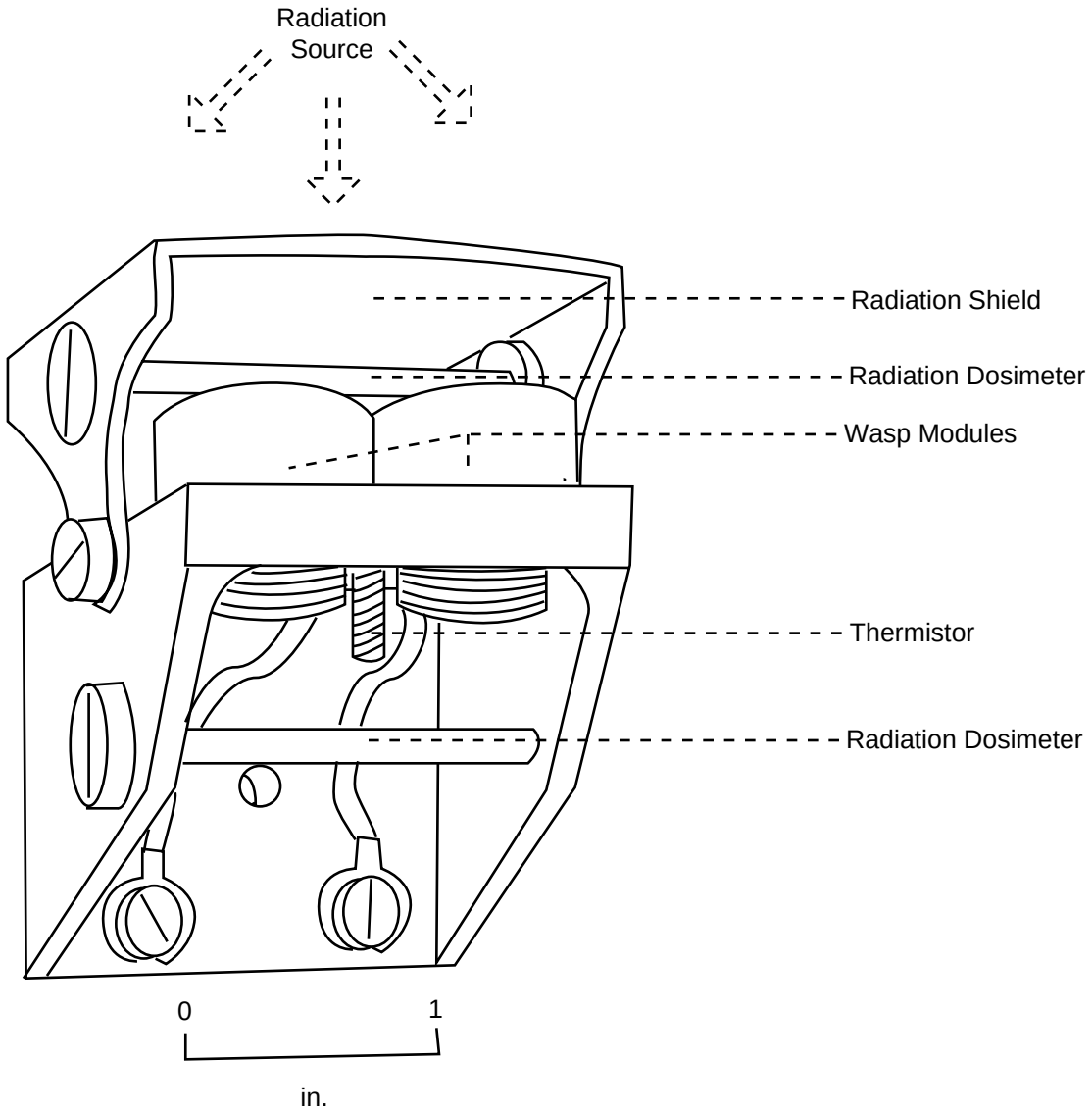
Temperature and radiation data

Related Ground-Based Hardware

None

Publications

- von Borstel, R.C. et al.: Mutational Response of Harbrobracon in the Biosatellite Experiment. *Bioscience.* Vol. 18 (No. 106): 598-601, December 1969.
- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.



Missions Flown Through 1990: **Biosatellite I/II (p. 44)**

Lysogenic Bacteria Experiment Package

Hardware Description

The Lysogenic Bacteria Experiment Packages are designed to grow replicate 1.2 ml cultures of two strains of lysogenic bacteria (*Escherichia coli* and *Salmonella typhimurium* P-22), without radiation and irradiated at three dose levels of gamma from ^{85}Sr. Sets of four special packages include a total of 96 bacteria growth chambers. Three contoured packages of sixteen chambers, 1.2–1.8 ml each, receive, respectively, mean total dose exposures of 265, 645, and 1,630 r. A fourth package of 48 chambers, 1.2 ml each, is for nonirradiated chambers. The packages are fabricated to conform to isodose lines at an appropriate distance from the point ^{85}Sr source. The chambers are sealed with nylon machine screws and silicone O-rings.

For loading, a single clone of each bacteria is grown overnight, and the resulting cultures are diluted to a final concentration of 120 cells/ml for *S. typhimurium* and 187 cells/ml for *E. coli.* Cultures are maintained in suspension in spinner flasks over ice throughout loading into experiment packages, in order to impose a two-hour lag time prior to the start of cell growth. *S. typhimurium* cultures are loaded into the top series of chambers, and *E. coli* are loaded into the chambers on the lower side of the package. Samples are made at the start and completion of loading procedures to confirm that no growth has occurred. Packages are kept on ice until mated with the spacecraft. LiF dosimeters are included in each package.

Specifications

Dimensions:	1.2 to 1.8 ml (chambers)
Weight:	Unknown
Power:	None
Chamber Capacity:	1.4 ± 0.3 ml

Data Acquisition

Radiation data

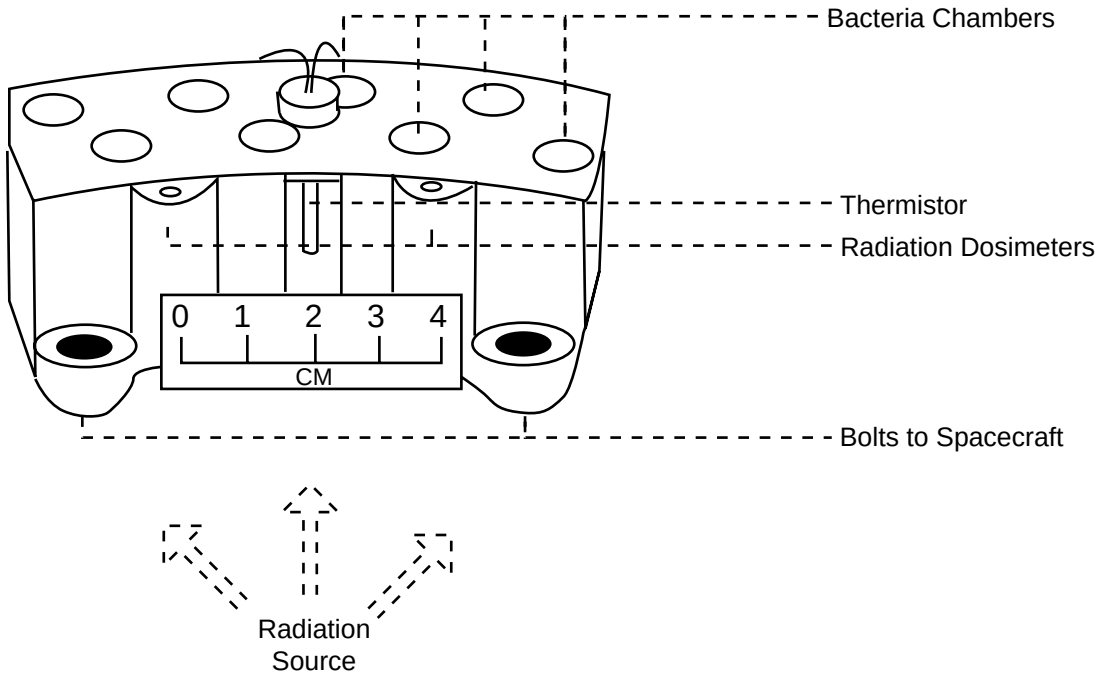
Related Ground-Based Hardware

None

Publications

- Mattoni, R.H.T.: Spaceflight Effects and Gamma Radiation Interaction on Growth and Induction of Lysogenic Bacteria. *Bioscience.* Vol. 18 (No. 106): 602-608, December 1969.

- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.



Missions Flown Through 1990: **Biosatellite I/II (p. 44)**

Hardware Description

The Neurospora (microorganism) Experiment Packages are designed to contain a large number of *Neurospora conidia* under conditions which prevent contamination and development of anoxia. Conidia are deposited on moist Millipore filters held on polypropylene screens to maintain both sterility and high humidity. A porous retaining ring is used to hold the Millipore filter in place on the screen and a polypropylene barrier is placed over the unit to contain each conidial sample within each disk. The sample holders are stacked in groups of ten and held together and attached to the module cap with three screws. The assembled module is screwed into a housing to complete the package assembly. The materials are autoclavable, biocompatible, and cause minimal radiation shielding and backscattering.

Radiation Dosimeters: Three independent systems of thermoluminescent dosimetry are used:

- EG&G CaF2:Mn Mini Thermoluminescent Dosimeters
- EG&G LiF Mini Thermoluminescent Dosimeters
- Con-Rad LiF-Teflon Disk Dosimeters (5 mm thick)

Neurospora (Microorganism) Experiment Package

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown

Data Acquisition

Radiation data

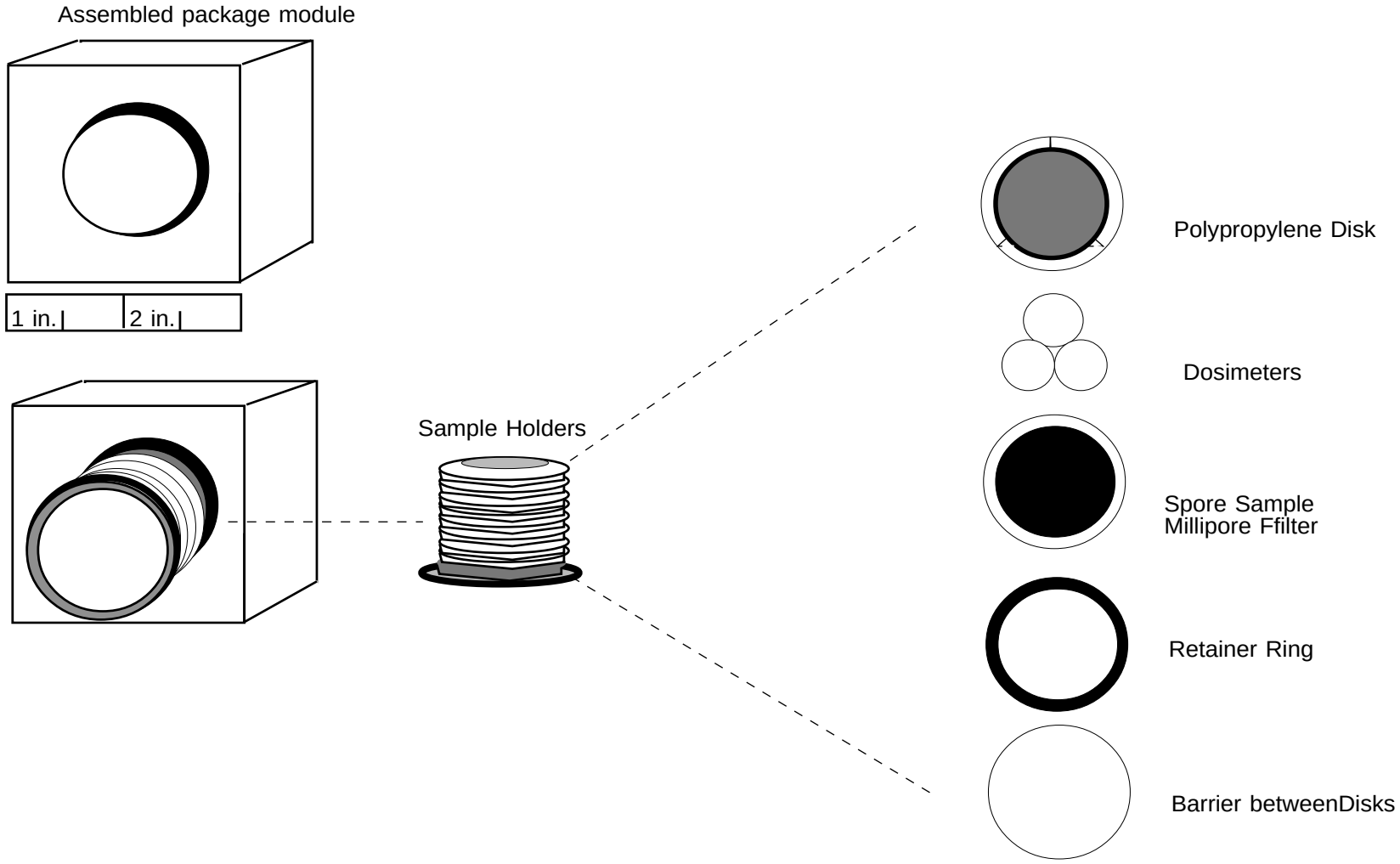
Related Ground-Based Hardware

None

Publications

- de Serres, F.J. and B.B. Webber: The Combined Effect of Weightlessness and Radiation on Inactivation and Mutation-Induction in *Neurospora crassa*. *Bioscience.* Vol. 18 (No. 106): 590-595, December 1969.

- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.



Missions Flown Through 1990: **Biosatellite I/II (p. 44)**

Passive Freezer (GN_2/Cryogenic Freezer)

Hardware Description

The Passive Freezer was used to freeze *Plant Canisters* on STS-34 to arrest plant growth inflight and keep plant specimens frozen until landing and recovery. The passive freezer uses GN_2 (gaseous nitrogen) as the cryogen. A Cryogenic Freezer Bag is used to insulate the freezer, and Cryogenic Gloves are used to protect the crew from extreme cold temperature while interacting with the Freezer.

Passive Freezer: The Passive Freezer consists of two flasks, one contained within the other. The freezer fits into a standard middeck locker and requires no power to operate. The space between the flasks is evacuated for thermal insulation. The inner flask contains calcium silicate which is used to absorb the LN_2 (liquid nitrogen) fuel source, hold it, and release GN_2 as heat is absorbed from the freezer cargo and surroundings. At the center of the calcium silicate is a cylindrical space where a *Plant Canister* or other cargo may be inserted. The inside diameter capacity is 8.9 cm and the length is 34 cm. The freezer temperature range is between -195 to -185 °C, and freezer holding time is eight days minimum. The freezer has no controls and contains only two moving parts: 1) a rotating neck plug can be removed from the freezer body to allow insertion or removal of samples and 2) a cap over the evacuation valve must not be removed.

Cryogenic Freezer Bag: The Cryogenic Freezer bag is used to insulate the Freezer and measures 17.5 inches in height and 10 inches in diameter. The bag is made of a quilted Nomex padding cover with Pyrel polyurethane padding. There are two handles made of Nomex webbing. Strips of velcro are mounted on the end pad of the bag for attachment of handles and gloves.

Cryogenic Gloves: The Cryogenic Gloves are used to protect the crew from the cold temperatures generated by the GN_2. The outer material of the gloves is made of Taslan-100% nylon which is resistant to most acids and chemicals, laminated with a 100% waterproof, semiporous membrane, having nine billion pores per square inch. The glove is insulated with Poly-olefin fiber, which is 65% olefin (polyporlene) and 35% polyester, thus having warmth without bulk. The insulation is machine washable and dryable. The liner is made of 100% cotton. The gloves are very lightweight, weighing only 6 oz per pair.

Specifications

Dimensions:	8.9 cm (inside diameter) x 34 cm
Weight:	13.5 kg (charged)
Power:	none
Volume (external):	$2.32 \times 10^{-2}\ m^3$
Volume (internal):	$2.1 \times 10^{-3}\ m^3$

Data Acquisition

None

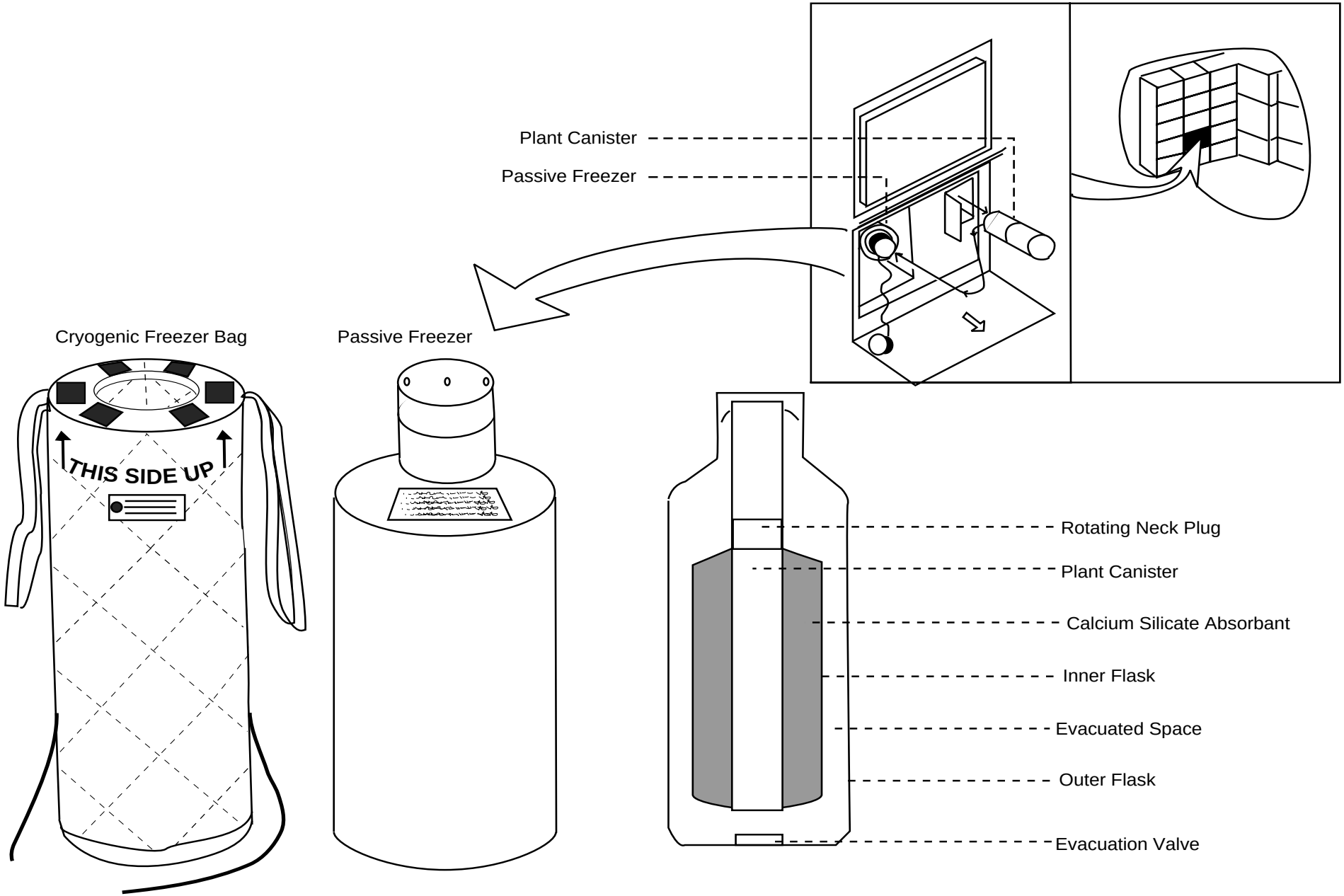
Related Ground-Based Hardware

LN_2 Charging Unit: Hardware required to charge freezer and replenish the liquid nitrogen supply.

Publications

- NASA-Ames Research Center, Internal Report ADR-88-50-021 Rev A.

Passive Freezer (GN 2/Cryogenic Freezer)



Missions Flown Through 1990: STS-34/GHCD (p. 97)

Pelomyxa (Amoeba) Experiment Package

Hardware Description

The Pelomyxa (amoeba) Experiment Package consists of polycarbonate resin chambers each divided into three 5 cc compartments, mounted inside a hollow box. Each compartment is separated by Lexan pistons with ethylene propylene O-rings. The first two compartments hold amoebae or paramecia that are mixed inflight via actuation of a Lexan shaft to which the pistons are attached. Further actuation mixes the first two compartments with the third compartment which contains fixative. Twenty-four chambers are mounted on five magnesium plates. Front, back, and side magnesium covers are mounted on these plates. The chamber shafts are spring loaded on one end and restrained by a multi-slotted face cam on the other end. When the cam, which is rotated by a high-torque motor, moves from one position to the next, chamber shafts are pushed into the cam slots to achieve "mix" or "fix" chamber actuations. These actuations, in turn, close microswitches which serve as verifications of actuations. Four of the chambers contain thermistors for measuring inflight temperatures. These data are telemetered to the various ground stations. High density foam pads are placed between chambers to damp vibrations during powered flight and re-entry. The total package is bolted to the aft plate of the Biosatellite module. A spacecraft timer initiates five sequential inflight actuations.

Specifications

Dimensions: Unknown
Weight: 15 lbs (total package)
Power: None

Data Acquisition

Inflight fixation

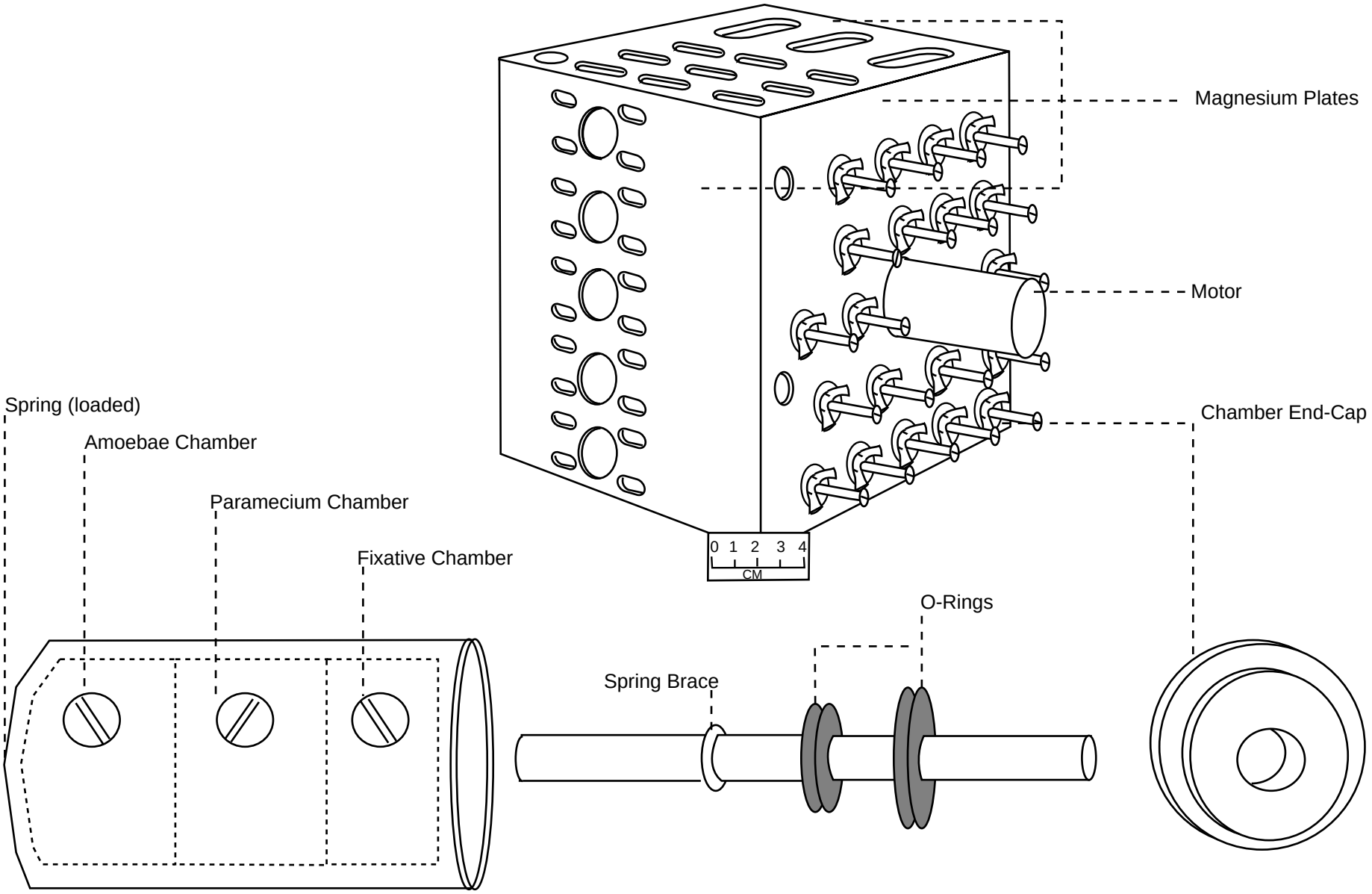
Related Ground-Based Hardware

None

Publications

- Eckberg, D.R. et al.: The Effect of Weightlessness on the Amoeba, *Pelomyxa carolinensis*-I. Materials and Methods. *Bioscience.* Vol. 18 (No. 106): 615-622, December 1969.

- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.



Missions Flown Through 1990: **Biosatellite I/II (p. 44)**

Plant Canister

Hardware Description

The Plant Canister consists of two hollow cans threaded together, constructed of anodized aluminum. There are four light-baffled holes in both the upper and lower cans, providing gas exchange for the plants contained within. The total canister assembly measures 355 mm tall and 82 mm in diameter and is contained in a hollow stainless steel container that contains a two-stage light filter. There is an end cap with a knob at one end to facilitate handling. Canisters are encased in plastic foam for placement in a middeck locker of the orbiter for flight. The foam is made of 2 lb/3 ft density, nominal 70 pores/inch Pyrel foam, which is a standard cushion material for middeck lockers, and the *Ambient Temperature Recorder*is utilized to monitor the temperature profile experienced during flight. Canisters can be fit into the *Passive Freezer*, to freeze tissue during flight.

For the Growth Hormone Concentration and Distribution (GHCD) payload on STS-34, kernels of the *Zea mays* sweet corn were used. Sterilized, individual kernels were wrapped in two 13 x 18 cm sheets of Whatman No. 1 filter paper. The first sheet was folded in thirds across the long dimension and served as a support for the kernel; this sheet was then rolled in the second sheet and inserted into a Teflon tube of 18 mm diameter, 335 mm in length. Thirteen of these dry wrapped kernels could be loaded into each of the two compartments of the Plant Canister. Seventeen hours before launch, 108 ml of sterile double-distilled water was added to the two compartments of the canister. For GHCD, a total of four canisters were utilized for flight, two of which were frozen during the flight.

Specifications

Dimensions: 8.27 cm (diameter) x 33.24 cm
Weight: 800 g
Power: None

Data Acquisition

None

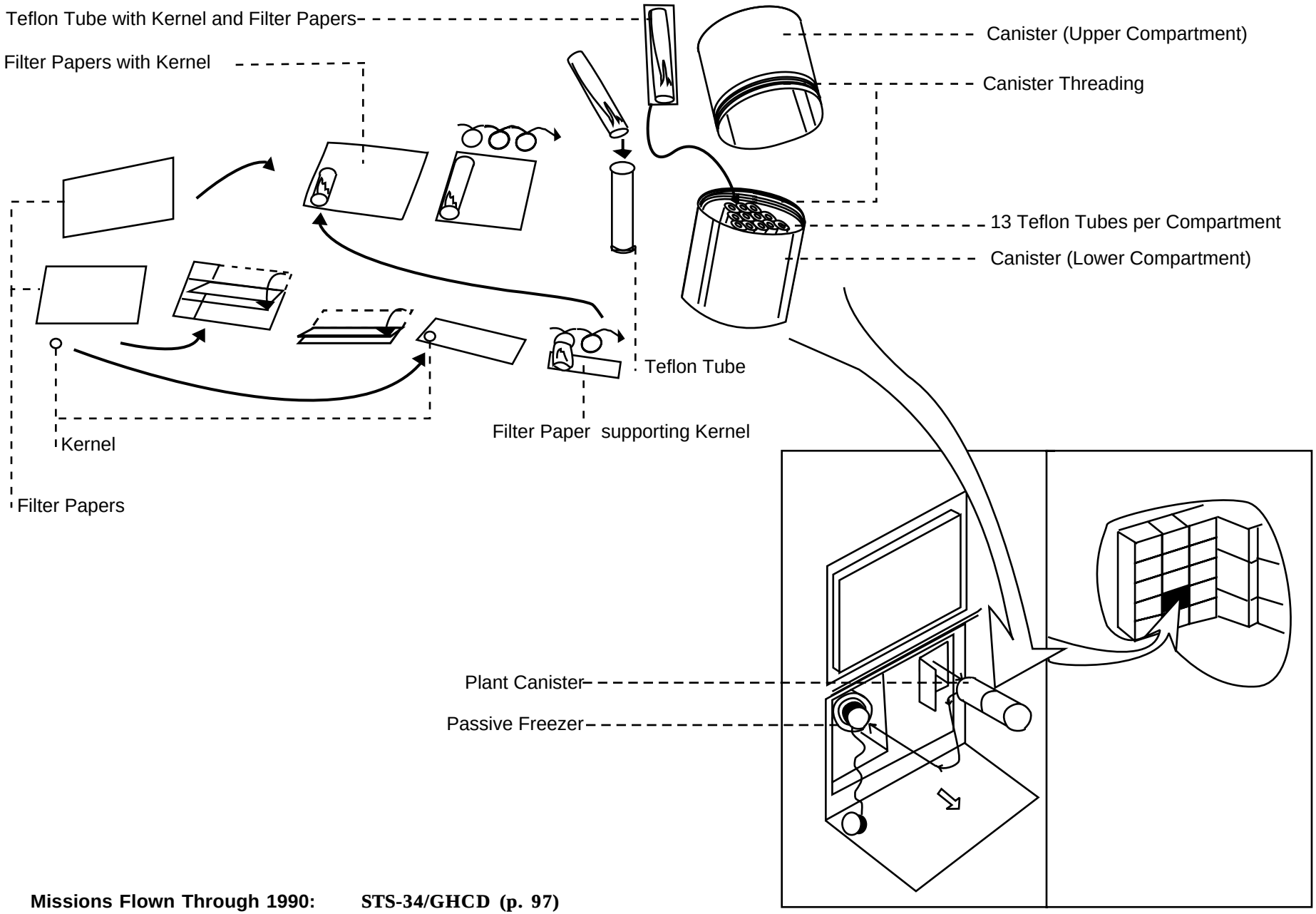
Related Ground-Based Hardware

Temperature-Programmed Incubator: Unit used to provide the flight temperature profile to ground controls. It is a computer-controlled incubator and allows control of the heating element by external relay.

Publications

- Schulze, A. et al. Studies on the Growth and Indole-3-Acetic Acid Content of *Zea mays* Seedlings Grown in Microgravity. *Plant Physiology*. Volume 100: 692-698, 1992.
- Berthhold, R. *Crew Familiarization Briefing, STS-34*. NASA-Ames Research Center. May 1989.

Plant Canister



Missions Flown Through 1990: **STS-34/GHCD (p. 97)**

Hardware Description

The Plant Growth Unit (PGU) is a self-contained system carried in the Orbiter middeck and designed to hold six removable Plant Growth Chambers. The PGU consists of the support components and a cavity for growing plants. The PGU is equipped with three 15 W plant growth lamps (Vita-Lite spectrum), a timer to provide day/night cycling, temperature sensors, electronically-controlled fans, heater strips for temperature modification, data-acquisition system, and internal batteries. The few system controls and displays appear on the exterior front panel. These include several status lights, a power switch, and a selectable digital temperature readout. Four switches that set the clock and a digital time display are located inside the unit. Temperatures and lamp status are recorded at intervals inflight by a tape recorder.

For environmental control, two thermostatically-controlled variable-speed fans draw air over the plant growth chambers. A temperature gradient decreasing from the top to the bottom of the chambers is maintained to prevent moisture condensation in front of the light. Diurnal temperature cycling is provided, with a chamber temperature of 78 ± 1 °F during the "daylight" and 74 ± 1 °F during the "night."

The PGU replaces a storage locker in the Orbiter middeck and can be placed into the Orbiter approximately twelve hours before launch and removed approximately one hour after landing.

Plant Growth Chamber: Each of the six chambers hold seeds or seedlings between sheets of moist filter paper-like material and consist of a metal alloy base and a Lexan cover which is sealed to the base using a gasket. Each chamber is airtight. The chamber base is fitted with a temperature probe in the center and two gas-sampling ports toward each end. Seeds or seedlings are planted in a "sandwich" support medium contained in the base. The chambers fit into the Plant Growth Unit which supplies all environmental control and power.

Lighting System: The lighting system consists of three fluorescent lamps containing phosphor lenses, reflector, aluminum housing, and associated circuitry. The filament and header designs are ruggedized; the lamp assembly is hermetically sealed with teflon tubing; and an indium-mercury amalgam is substituted for elemental mercury. The light intensity over the four middle plant growth chambers is about 75 µmol/m^2/sec and over the two outside chambers about 48 µmol/m^2/sec. Diurnal cycles are adjustable.

Specifications

Dimensions:	52 x 45.9 x 27.4 cm
Weight:	27.2 kg (59.84 lb)
Power:	28 VDC; day 81.2 W; night 47.6 W
Chamber Size:	19 x 5 x 22 cm
Irradiance:	75 µmol/ m^2/sec Photosynthetic Active Radiation
Spectrum:	Fluorescent (Vita-Lite)
Thermal Control:	Temperature in PGU can be controlled only above ambient

Data Acquisition

Temperature and lamp status (tape recorder)

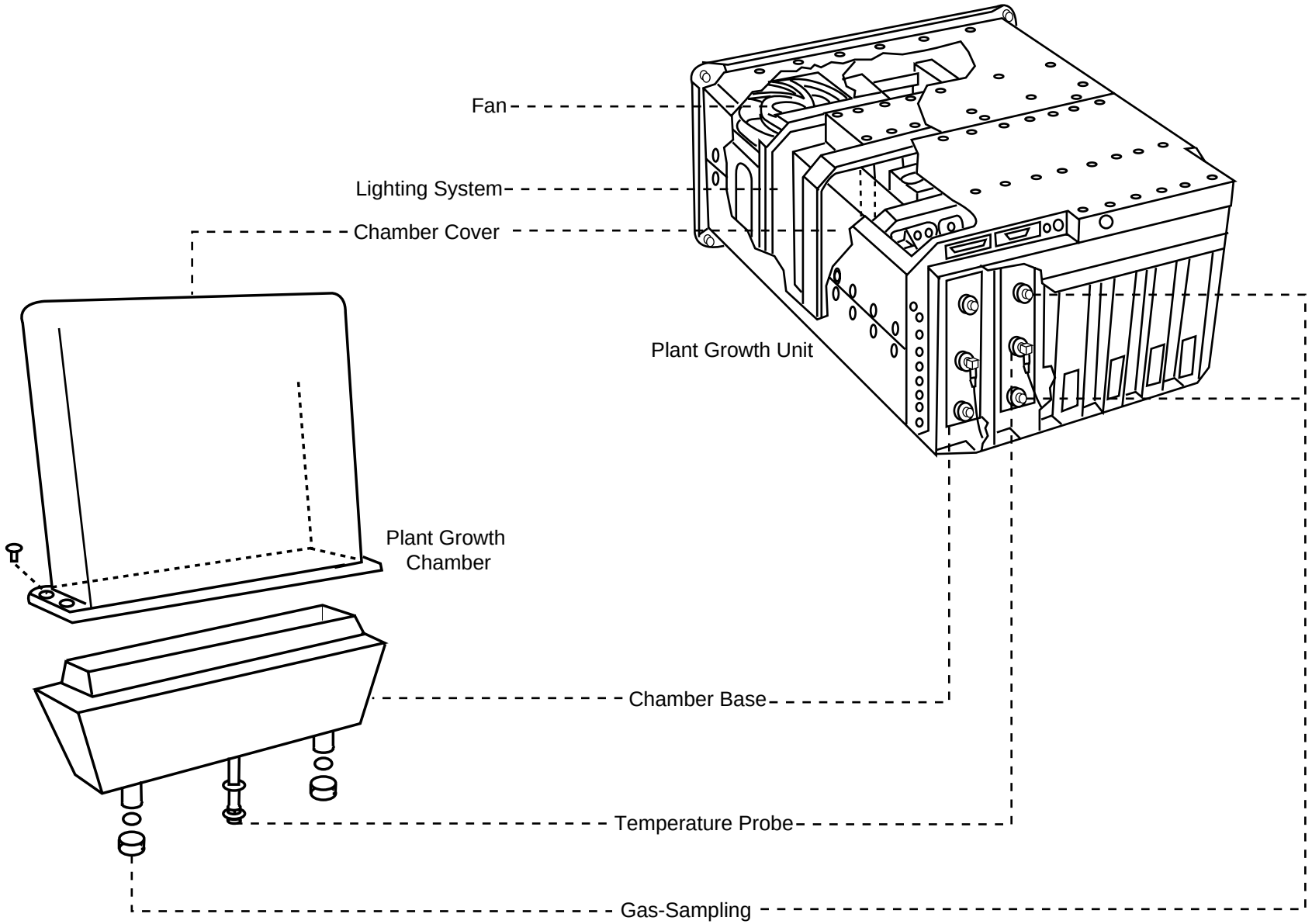
Related Ground-Based Hardware

Ground Support Console: Used to check all PGU systems for proper operation prior to launch and to readout all recorded temperature data postflight. The system, housed in a standard 19 inch electronics rack, includes the required power supplies, meters, tape deck, computer, and printer for numeric printout of flight data.

Publications

- Cowles, J.R. et al.: Growth and Lignification in Seedlings Exposed to Eight Days of Microgravity. *Annals of Botany*. Vol. 54 (Suppl. 3): 33-48, November 1984.
- Cowles, J.R. et al.: Microgravity Effects on Plant Growth and Lignification. *Astro. Lett. and Communications* Vol. 27: 223-228, 1988.
- Olcott, T.M. and C.E. Rudiger: *Lockheed Involvement in Shuttle Life Sciences Flight Experiments*. Lockheed Missiles and Space Company, Inc., Advanced Systems Division, Palo Alto, pp. 2-4.

Plant Growth Unit (PGU)



Missions Flown Through 1990: **STS-3/OSS (p. 82), STS-51F/SL-2 (p. 94)**

Hardware Description

The Primate Life Support System includes the urine transport system, restraint system, food pellet dispenser, water dispenser, feces collector, light assembly, camera, and environmental life support, camera and lighting controllers. Capsule air is controlled at sea level pressure with partial oxygen pressure at nominally 20% of the gas mixture. CO_2 is removed by lithium hydrogen canisters, and other trace gases are controlled by activated charcoal.

Urine Transport System The urine transport system consists of a catheter designed for thirty-day use and a transport system.

Urine Analyzer The urine analyzer receives samples from the *Urine Transport System.*

Restraint Couch System The restraint system consists of a couch and restraint garment.

Pellet Feeder Dispenser The feeder can operate automatically or in conjunction with the *Primate Psychomotor Test System.*

Light Assembly: The light assembly consists of a primary and backup incandescent bulb which provide a 12/12 hour day/night cycle and a 30/1 day/night ratio of intensity. A light sensor is included in the capsule instrumentation for verification of the light condition in interpreting physiological observations.

Water Dispenser: The water dispenser is designed to allow sucking of water during orbital flight. The 30 ml dispenser is filled once each hour in the capsule day mode, and once every three hours during the night mode. Ground command capability provides for immediate refill of the dispenser at any time, and for a maximum water mode in which the dispenser is filled every hour during the night and day cycles. The dispenser contains a secondary solenoid valve to prevent unmeasured flow should the primate consume water as it is being filled. A fuel cell fed by hydrogen and oxygen produces water and power for the satellite while in orbit.

Feces Collector: To collect fecal material in flight, cabin air is drawn through a foam lining to effect distribution at its bottom. Air is drawn into the collector through holes close to the anus to provide a kind of pneumatic transfer. The tube is attached to the animal by means of a belly band restraint with a large external ring that interfaces the animal to the collector. The collector is mounted to the couch frame.

Camera: The camera is used to record still photographs every twenty minutes throughout the flight, and as controlled by the psychomotor test system. It can operate up to four frames per second. A prism is used to permit photography of the animal's eyes and head. A unique auxiliary lens over a portion of the entrance pupil of the camera's objective focuses the clock image onto a portion of each picture.

Environmental Life Support, Camera and Lighting Controllers: Life support, camera and lighting controllers are incorporated into the life support system to program its various components in response to clock signals, to the psychomotor programmer, and to ground commands.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown
Temperature: 20.75 to 21.5 °C
Light Intensity: 6 lux (daylight)

Water Dispenser Capacity: 30 ml/hour (max)

Data Acquisition

Photographic documentation, environmental data

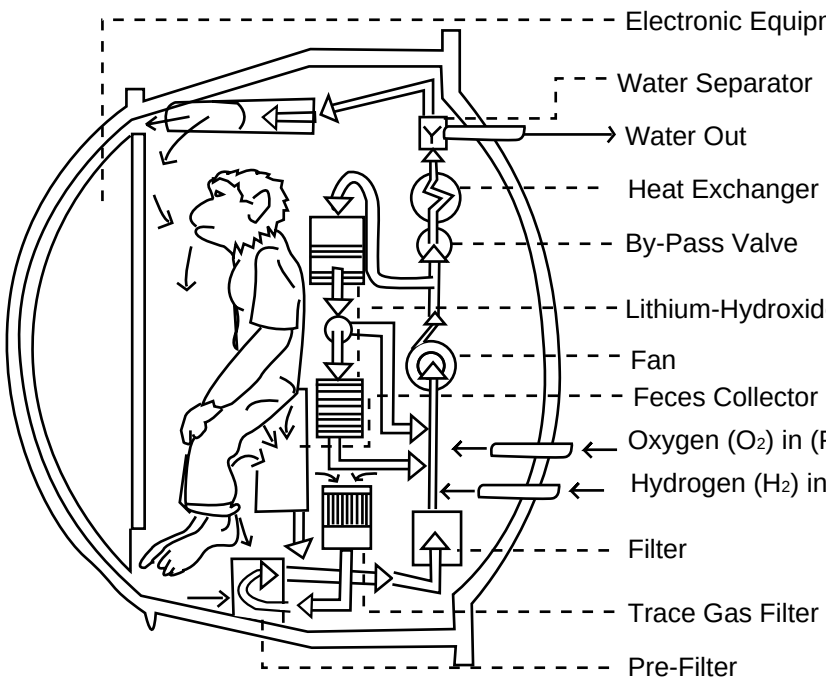
Related Ground-Based Hardware

Water Supply Unit: To fill primate water dispenser and receive metabolic wastes during testing.

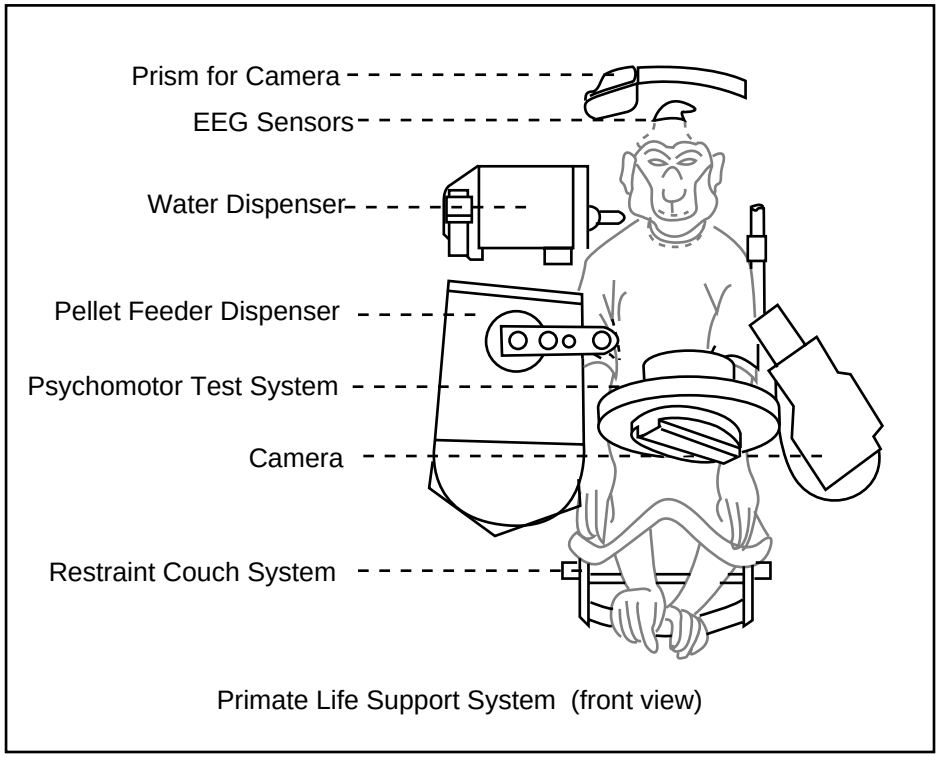
Payload Transporter: To transport the experiment assemblies while maintaining proper environmental conditions.

Publications

- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.
- Mains, R.C.: *Report on Primate Restraint and Acceleration Protection System, Reentry Acceleration Data, and Flight Diet Composition for U.S. Biosatellite III Project.* NASA-Ames Research Center. February, 1980.
- Adey, W.R. and P.M. Hahn: Introduction-Biosatellite III Results. *Aerospace Medicine.* Vol. 42: 273-280. March, 1971.



Primate Capsule



Primate Life Support System (front view)

Missions Flown Through 1990: **Biosatellite III (p. 53)**

Primate Life Support System: Pellet Feeder Dispenser

Hardware Description

The Pellet Feeder Dispenser is powered electrically for flight and can operate in conjunction with the *Primate Psychomotor Test System.* As a result of correct performance of behavioral tasks and during the "free" feeding period, the subject can obtain a pellet from the feeder by pressing a lever with a force of 1.5 kg. Pellets can also be dispensed by ground command as necessary. The total pellet count is the sum of counts from these two channels. Each pellet dispensed is indicated by a step change in the channels' output voltage to a maximum of 63 pellets when the voltage recycles to zero.

The feeder is designed to carry eight rolls of teflon tape, each with 230 pellets adhesively attached. The pellets are stuck onto rolls of Mylar tape, and the tapes are wound onto spools in the dispenser. The feeder contains eight pellet rolls for a total of 1,840 food pellets for the planned thirty-day mission. Pellets are dispensed one at a time through a slot where the monkey can grab them. The monkey is provided with sixty pellets per day: twenty per day are offered *gratis,* and the remaining 40 serve as a reward for correctly performing psychomotor, behavioral tasks. The handle, which operates much like a slot machine, presents one pellet from each roll in sequence in its respective slot. By this concept, it is hoped that mechanical blockage will never obstruct a large proportion of food availability.

Food Pellets: The primate food pellet has a specified hardness, weight per pellet, friability, nutritive composition, and size. The diet is formulated and manufactured by Pillsbury and consists of a high-protein casein base augmented with Terramycin, vitamins, and trace elements. Pellet composition is approximately 14% protein, 9% fat, and 77% carbohydrates. The diet produces a slightly acidic urine which keeps calcium ions in solution for measurement in the *Urine Analyzer*. Psyllium husk is added to produce a firmer stool. The resulting nonhydroscopic pellets are spray-coated on one side to improve their adherence to the feeder tapes. Each pellet contains 6.7 calories.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown (electrically operated)
Capacity: 230 pellets x 8 rolls = 1840
Pellet Weight: 2.25 g/pellet

Data Acquisition

Pellet dispenser counts

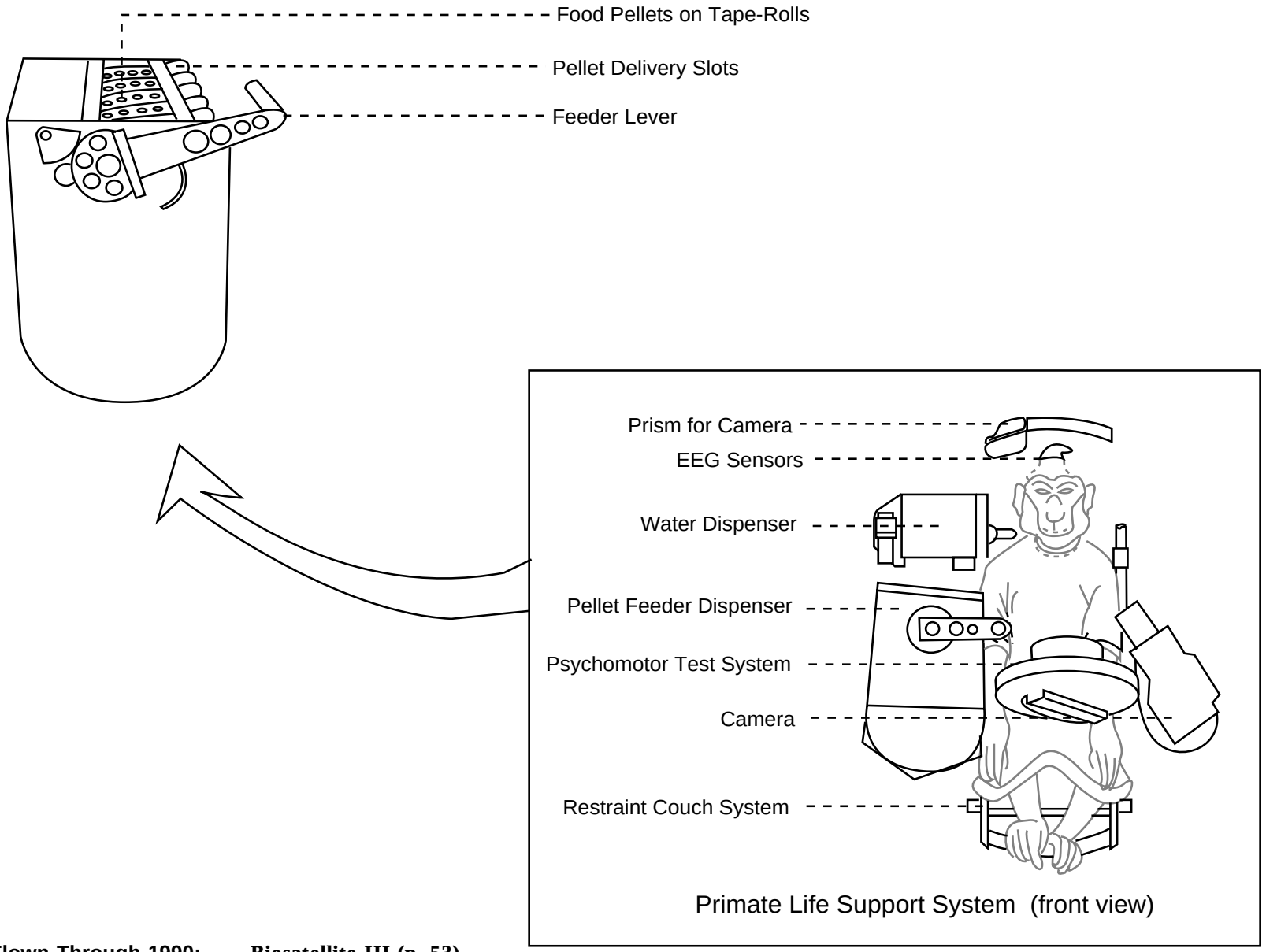
Related Ground-Based Hardware

Mechanical Pellet Feeder: A mechanical unit identical in design supported numerous evaluation tests and was similarly flight qualified; electrical unit was chosen for flight because of reliability and consistent handle force.

Publications

- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.
- Mains, R.C.: *Report on Primate Restraint and Acceleration Protection System, Reentry Acceleration Data, and Flight Diet Composition for U.S. Biosatellite III Project.* NASA-Ames Research Center. February, 1980.
- Adey, W.R. and P.M. Hahn: Introduction-Biosatellite III Results. *Aerospace Medicine.* Vol. 42. March, 1971, pp. 273-280.

Primate Life Support System: Pellet Feeder Dispenser



Missions Flown Through 1990: **Biosatellite III (p. 53)**

Primate Life Support System: Restraint System

Hardware Description

The restraint system functions to protect the primate during launch and re-entry environmental stresses, protect the physiological instrumentation from the monkey, and provide comfortable restraint during periods as long as forty days. The restraint system consists of an aluminum frame couch to which is attached to the garment restraint system. Subjects are conditioned to the restraint system while simultaneously learning the behavioral tasks, over a four-month period.

Couch: The primate couch is constructed of lightweight aluminum and features a foot rest and foot separator, an aluminum box to contain four heparin bags, and a back plate to which experiment equipment is mounted. The footrest has a center divider that prevents the animal's feet from crossing over, thus protecting the galvanic skin response leads (dropped from the experiment before flight). The footrest also prevents the animal from exerting a force with his feet directly on the inside surface of the capsule. The forward portion of the suit zips into position on the couch, attaching to a hammock style backrest laced along the full length of the couch rails.

Garment Restraint System (Hammock): The hammock restraint garment for the animal is tightly laced to the couch frame between the side rails. The rails follow the shape of the monkey in a sitting position. The hammock has a foam pad head rest attached to it and an opening for feces elimination. This opening and the lower back and pelvic area are covered with a fabric-covered foam "comfort pad." The "soft" style of the restraint maximizes the comfort factor while still adequately protecting the animal's implants and the spacecraft interior. The restraint also serves to locate the animal over the feces can, which is attached by a flexible duct (to allow vertical movement) to the restraint.

Garment Restraint System (Jacket): The forward portion of the garment is a nylon suit which covers the body from the neck area down, with arms free. Legs are closely held in a forward position, with the feet located by a nonmetallic rest at the end of the couch frame. The jacket is closed in the back with a Velcro fastener strip and has lacings over each shoulder to allow adjustment of the size of the neck opening. The lower border of the jacket extends down over the legs to prevent the monkey from reaching sensors. Full-length zippers on each side of the garment serve to attach it to the hammock and provide a "quick-release" feature for removing the monkey from the couch.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: None

Data Acquisition

None

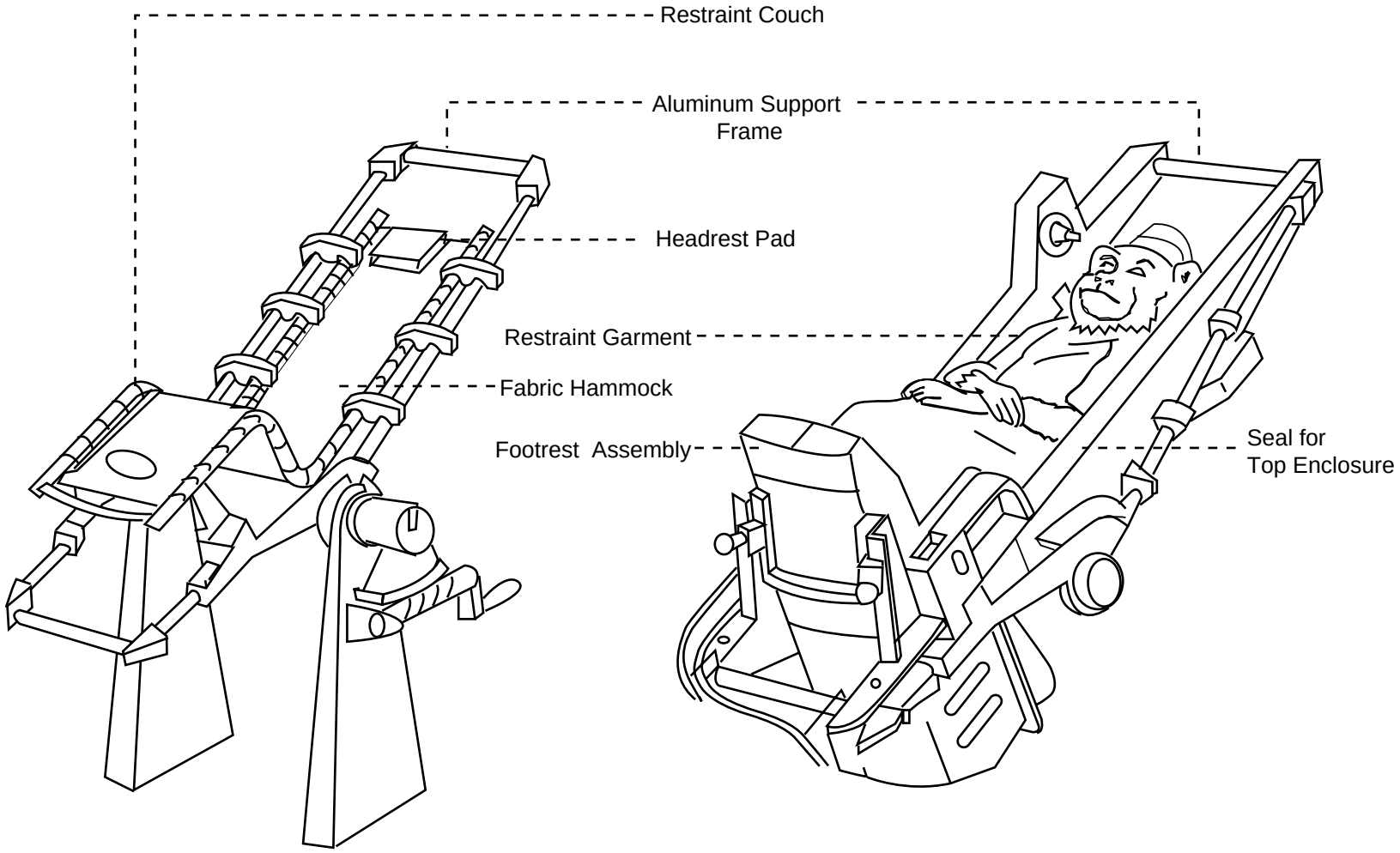
Related Ground-Based Hardware

Simulator Assembly: An enclosure built around the couch to provide an enclosed environment for the primate for capsule adaptation, feeding/watering, day/night lighting, psychomotor training, baseline, physiological data, etc. during countdown and for subjects on the ground.

Couch Holding Fixture: To hold and rotate the couch during launch and recovery, while maintaining the enclosed environment for the animal.

Publications

- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.
- Mains, R.C.: *Report on Primate Restraint and Acceleration Protection System, Reentry Acceleration Data, and Flight Diet Composition for U.S. Biosatellite III Project.* NASA-Ames Research Center. February, 1980.



Restraint Couch with Holding Fixture

Restraint Couch with Simulator Assembly

Missions Flown Through 1990: **Biosatellite III (p. 53)**

Hardware Description

The Jet Propulsion Laboratory (JPL) Urine Analyzer features miniaturized hardware elements to sample urine and measure concentrations of calcium, creatine, and creatinine. The unit is comprised of a hermetically sealed magnesium metal case plated with gold and a thin surface layer of silicon rubber, with approximately 5,300 cm^3 of usable volume. The case is pressurized to 650 torr with nitrogen gas and contains a urine sample accumulator, a calcium analyzer, a creatine-creatinine analyzer, reagent storage bags, logic sequencers, a data handling system, and power converter.

When the *Urine Transport System* pumps its measured 10 ml quantities, the sample accumulator withdraws a 1 ml sample downstream. These samples are collected over a six-hour period, at the end of which the analysis cycle is initiated. Two microsyringes, each with a capacity of 85 µl, function as the calcium and creatine-creatinine analyzers. Syringe plungers are motor-driven, and by suitable valving the quartz barrels can be filled with appropriate volumes of urine and regent. Syringe contents can then be pumped into and out of a small mixing chamber several times, with the quartz barrels serving as a cuvette to measure the optical density or fluorescence intensity of the reaction mixture. At the end of the analysis, the products are emptied into a urine line leading to the urine storage tank. In addition to urine analyses, the unit performs a calibration analysis once every 24 hours. The unit can store enough reagent to preform this analysis sequence for thirty days.

Calcium: Calcium concentrations from samples and knowledge of total urine quantity on a related timeline provide the basis for calculating the total calcium excretion through urine during the mission. Calcium in the sample is detected optically after mixing with a chemical reagent, calcein, which produces a fluorescent complex, the intensity of which is an indicator of concentration.

Creatine-Creatinine: Creatine and creatinine are obtained by initially measuring free creatinine optically from a color development of urine mixed with picrate solution. A portion of the sample is treated with acid at high temperatures to convert the creatine to creatinine, and the color development process is repeated. Creatine is determined as total creatinine less the original creatinine.

Specifications

Dimensions:	14 x 18 x 30 cm
Weight:	6.8 kg
Power:	6.5 W
Capacity:	30 days stored reagent
Sample Rate:	6 hours

Data Acquisition

Calcium, creatinine, and creatine level in urine, telemetered to the ground during the flight.

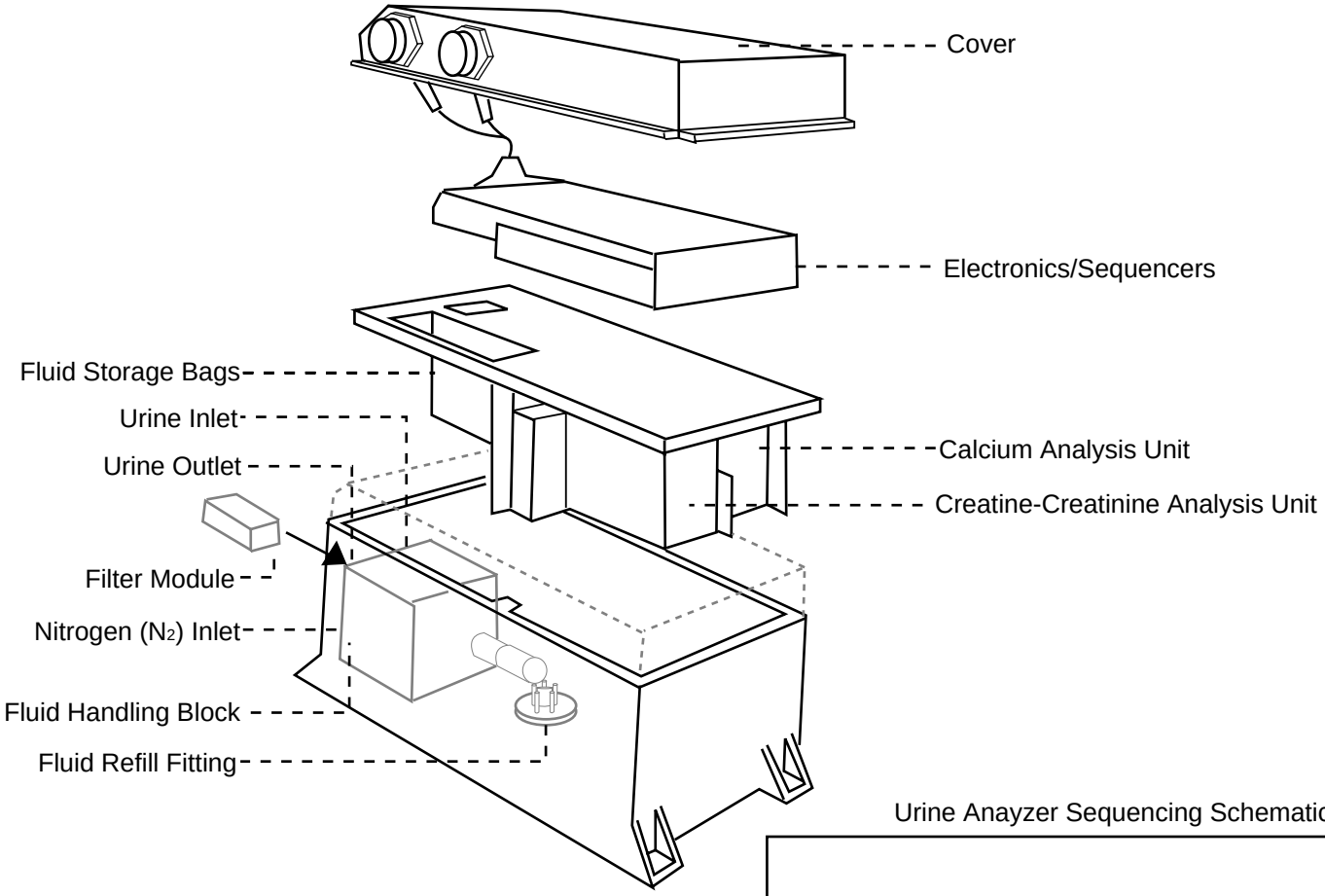
Related Ground-Based Hardware

Auxiliary Ground Equipment: Console for processing data telemetered during the flight and simulating hardware functions during verification tests, including timing commands, telemetry readout.

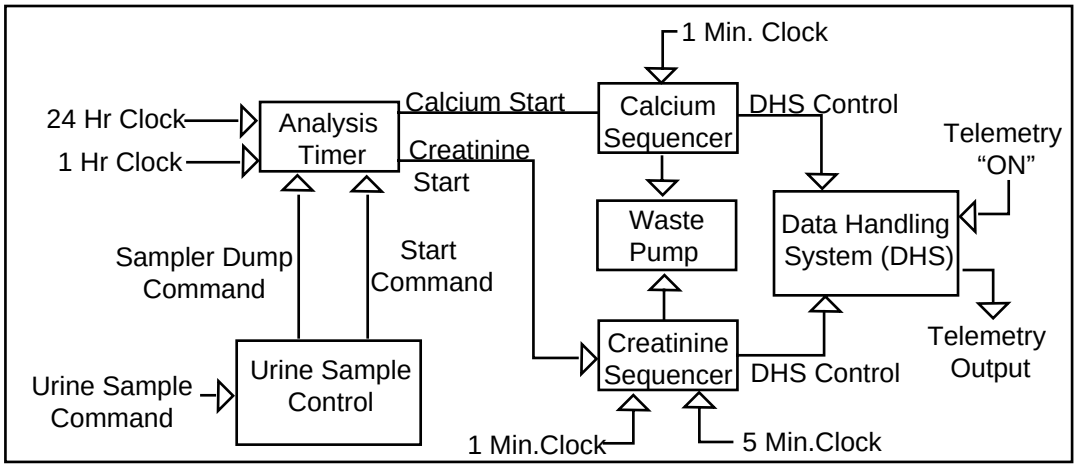
Vacuum Pump/Plumbing System: To simulate metabolic waste and test fluid handling for unit operation.

Publications

- Pace, N. et al.: Biosatellite III Urine Analysis System Characteristics. *Urine Excretion Rats of Calcium, Creatine, and Creatinine in the Test Monkeys and Flight Monkeys Used for NASA Biosatellite III.* NASA CR 114425: 9-15, 1971.
- Stuart, J.L.: Bioengineering in Space-The Biosatellite Urinalysis Instrument. NASA-Jet Propulsion Laboratory. Technical Report 32-1400. July 1, 1969.
- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.



Urine Anayzer Sequencing Schematic



Missions Flown Through 1990: **Biosatellite III (p. 53)**

Primate Life Support System: Urine Transport System

Hardware Description

The Urine Transport System consists of an implanted catheter, urine collector, actuator assembly, and transport subsystem. Urine is collected, measured, and transferred downstream at hourly intervals to the *Urine Analyzer* located in the adapter section of the Biosatellite.

Catheter: The silastic urine catheter is implanted in the monkey bladder, exteriorized through the perineum, and mated to the urine transport system at the side of the couch. The catheter is designed to remain in place for thirty days.

Collector: The urine collector is essentially a container with a flexible diaphragm and a net capacity of 100 ml. The collector passively receives the urine produced by the animal. Once an hour, the collector is emptied by a peristaltic pump into the actuator assembly. The pump is started by an automatic signal.

Actuator Assembly: The actuator assembly delivers 10 ml volumes of urine downline to the *Urine Analyzer* with piston action, as long as urine is received from the peristaltic pump. If the final filling of the actuator is less than 10 ml, that urine remains in the actuator until the next hour pumping sequence is started. Spacecraft telemetry reports the number of hourly 10 ml "dumps" of the actuator to provide a measure of urine excretion rate. Each dump cycle is indicated by a corresponding telemetric voltage increase of 0.3 ± 0.075 V. Sixteen dumps increase the voltage in even increments from 0 to 4.5 V, after which the voltage recycles to zero. For any given hour there is an uncertainty of ± 10 ml; however, in any summation of consecutive hour values, the uncertainty always remains 10 ml for the the total summated period.

Transport Subsystem: The urine transport subsystem is constructed of nonpathogenic tubing totaling 4.8 m in length, a pressure-operated emergency valve and bag in case of downline blockage, a filter screen with capacity for the entire flight, the peristaltic pump, a solenoid valve, a series of quick disconnects between the capsule and adapter, and an evacuated titanium storage tank. A separate, smaller urine tank, light in weight and strong enough for evacuation, stores urine until it is analyzed by the *Urine Analyzer.* Tubing internal diameter ranges from 2.3 mm to 6.4 mm, and the dead space volume between the monkey and the analyzer is 105 ml.

Specifications

Dimensions:	Unknown
Weight:	Unknown
Power:	None
Collector volume:	100 cc
Actuator Volume:	10 cc
Actuator Accuracy:	± 10 ml

Data Acquisition

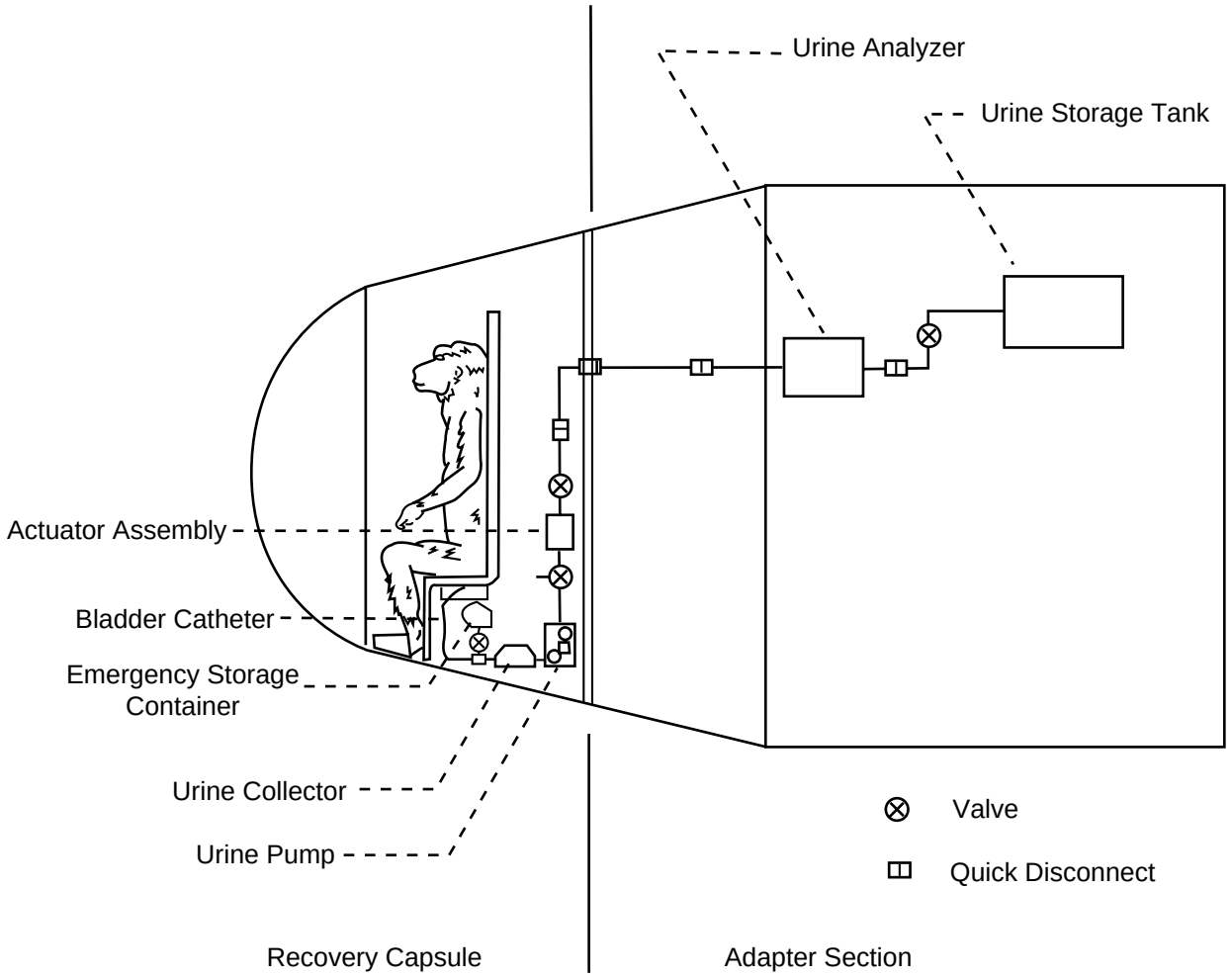
Urine excretion rate, telemetered during the flight.

Related Ground-Based Hardware

Urine Transfer/Measurement Unit: To supply sterile simulated urine to the transport and measurement assembly, and collect the effluent to determine functional integrity of the system.

Publications

- Pace, N. et al.: Biosatellite III Urine Analysis System Characteristics. *Urine Excretion Rats of Calcium, Creatine, and Creatinine in the Test Monkeys and Flight Monkeys Used for NASA Biosatellite III.* NASA CR 114425: 9-15, 1971.
- Mains, R.C.: *Report on Primate Restraint and Acceleration Protection System, Reentry Acceleration Data, and Flight Diet Composition for U.S. Biosatellite III Project.* NASA-Ames Research Center. February, 1980.
- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.



Missions Flown Through 1990: **Biosatellite III (p. 53)**

Hardware Description

The primate onboard Biosatellite III is instrumented with physiological sensors including implanted electroencephalogram (EEG), electromyogram (EMG), electrooculogram (EOG), electrocardiogram (EKG), impedance pneumogram (ZPG), brain and body temperature electrodes, and blood pressure sensors. Transducers in the spacecraft measure capsule total pressure, partial pressures of oxygen and carbon dioxide, air temperature, pellet and water consumption, urine production, task performance, day/night light status, and any changes in capsule altitude. In total, there are 33 channels of physiological information (including urine data). Telemetry data and data from the onboard flight recorder and camera combine to form a uniquely complete record of the animal's health, environment, and behavioral responses in weightlessness.

EEG: The EEG electrodes, which collect ten individual measurements, are deep implants through the top of the skull, potted into a head cap of Kadon.

EOG, EMG, EKG, ZPG: These sensors are implanted in muscle tissue with short exteriorized leads.

Brain and Body Temperature: The brain temperature sensor is installed as part of the head cap assembly and is located in the posterior superior portion of the corpus collosum. The body temperature sensor is attached to the urine catheter below the bladder.

Blood Pressure Sensors: Blood pressure sensors are connected to the implanted catheters, which extend to four separate cardiovascular sites: the central artery, tibular artery, the pulmonary artery, and the central vein. Two catheters are inserted into each leg near the medial surface of the knee and routed down each leg and covered with a nylon mesh "legging" before they connect to the fitting on the hammock. This instrumentation is connected mechanically to the four teflon catheters that enter the body at the animal's thigh. Pressures are measured at the transducer assembly, which is external to the animal. A set of solenoid pumps inject a small volume of heparin into each catheter line at one-minute intervals to maintain the catheter tip (within the animal) clear of any clogging or clotting.

Signal Conditioners: Signal conditioners for the low-level physiological outputs are located on the back of the animal's couch to minimize lengths of signal leads and provide practical interfaces for the animal/couch assembly with the rest of the flight system. Each sensor (electrodes, thermistors, pressure transducers, etc.) converts the acquired physiological or environmental variable to an electrical analog. This analog is conditioned (i.e. amplified, counted, etc.) to a voltage signal compatible with the telemetry system which then digitizes the data, codes it, and transmits it to the ground.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown
Channels: 33
Output Signal: 0–5 Volts

Data Acquisition

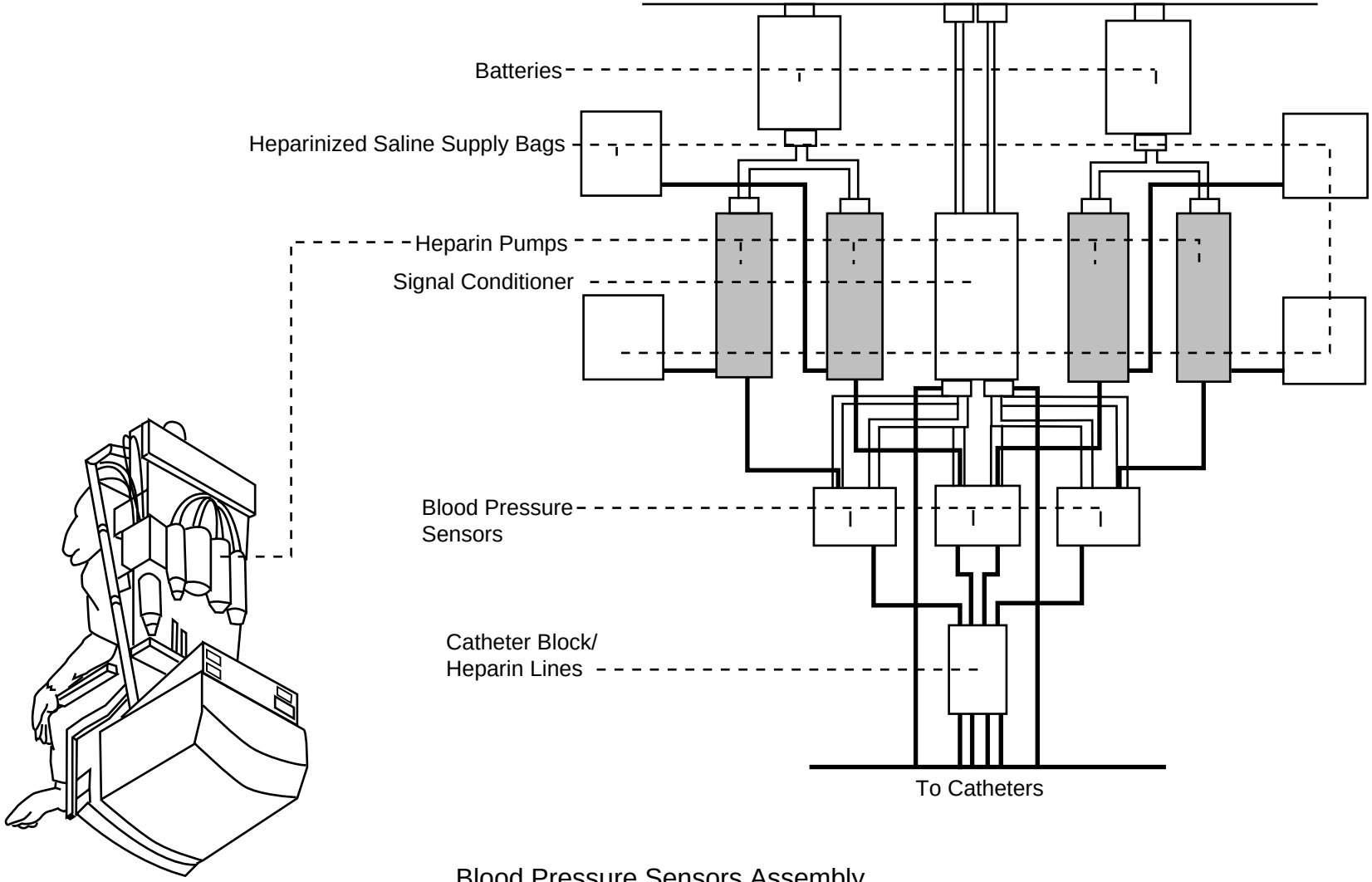
Brain and body temperature; blood pressure; EEG, EKG, EOG, EMG, ZPG

Related Ground-Based Hardware

None

Publications

- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.
- Mains, R.C.: *Report on Primate Restraint and Acceleration Protection System, Reentry Acceleration Data, and Flight Diet Composition for U.S. Biosatellite III Project.* NASA-Ames Research Center. February, 1980.
- Adey, W.R. and P.M. Hahn: Introduction-Biosatellite III Results. *Aerospace Medicine.* Vol. 42: 273-280. March, 1971.



Blood Pressure Sensors Assembly

Missions Flown Through 1990: **Biosatellite III (p. 53)**

Hardware Description

The Primate Psychomotor Test System consists of the display-response panel and the logic and control unit. The system is designed to test the monkey in two behavioral tasks: one involves delayed matching of symbols for testing of recent memory and perception; the other tests coordination of eye and hand in detecting coincidence of two rapidly rotating objects. Correct responses for either task arms the *Pellet Feeder Dispenser* with a food reward.

Panel: The psychomotor panel is positioned directly in front of the animal, positioned for easy reach and eye focus. The apparatus consists of five switches and two overlapping revolving disks. The panel displays the Nixie tube switches for the delayed matching task and the rotating concentric discs for the visuomotor task.

Logic and Control Unit: The psychomotor logic and control unit is a separate capsule component and contains the electronics for the psychomotor task operations and its associated data formatting. This "housing" also has control interfaces with a number of spacecraft components within the capsule, such as the camera, tape recorder, and feeder.

Behavioral Tasks: Twenty trials of delayed matching task are nominally followed by twenty trials of visuomotor task. Nominally each trial lasts forty-five seconds. Either task can be initiated or canceled by ground command. Every correct response produces a brief flash of the secondary reward lamp, located near the psychomotor panel. A food pellet can be obtained by operating the feeder lever arm after every second correct response. A maximum of forty pellets per day can be obtained from successful task performance.

Delayed Matching (DM) Task: The five switches for use in the DM task are transparent windows with overlaying neon tubes capable of displaying symbols. During each DM trial, the animal is required to respond by touching the center window display (A) within five seconds thereby extinguishing the display. The symbol presented in the center display is selected randomly from a set of four (square, X, circle, triangle). Approximately eighteen seconds later, the four symbols are displayed in a random pattern in the peripheral windows (B, C, D, E). In a correct response, the subject touches the window displaying the symbol matching the just extinguished symbol of window A. Incorrect choice or non-response to either presentation extinguishes the display and terminates the trial.

Visuomotor (VM) Task: In the VM task, two plastic disks lie one in front of the other and rotate in the same direction at approximately 85 revolutions per minute. The front disk is transparent to permit the subject to track a button on the rear disk. This button is exposed when the hole on the surface disk coincides with it. The subject presses the button for correct response at coincidence. Coincidence occurs approximately every two seconds during the trial.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown

Data Acquisition

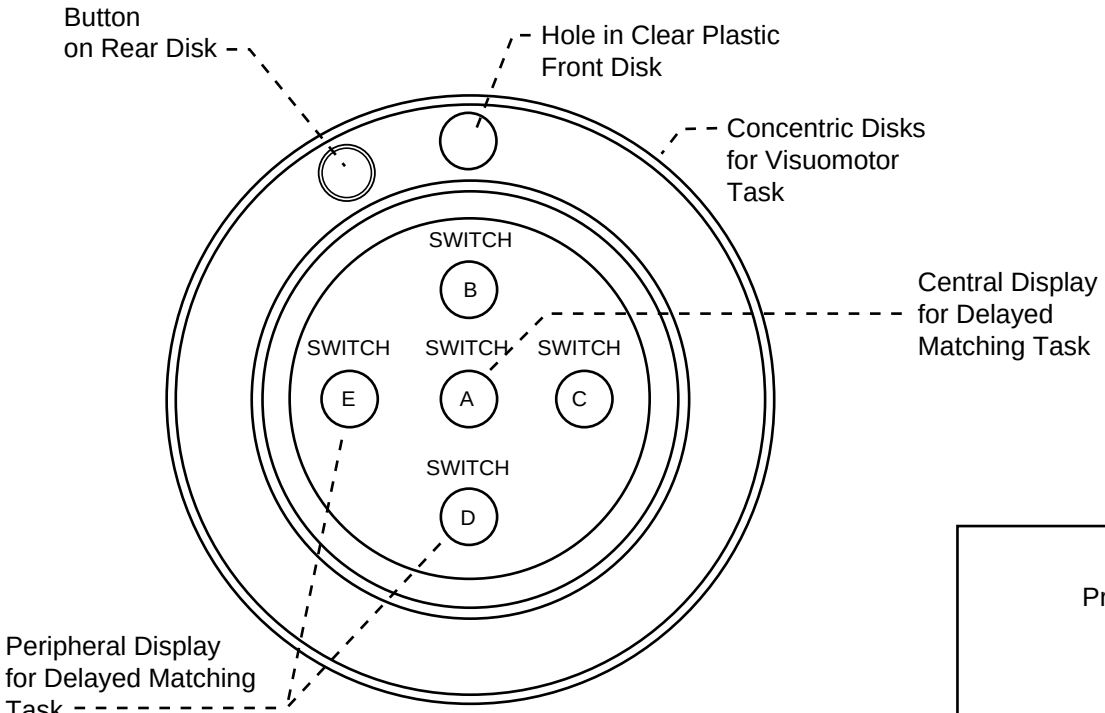
Task responses (see description)

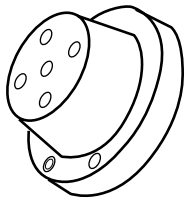
Related Ground-Based Hardware

None

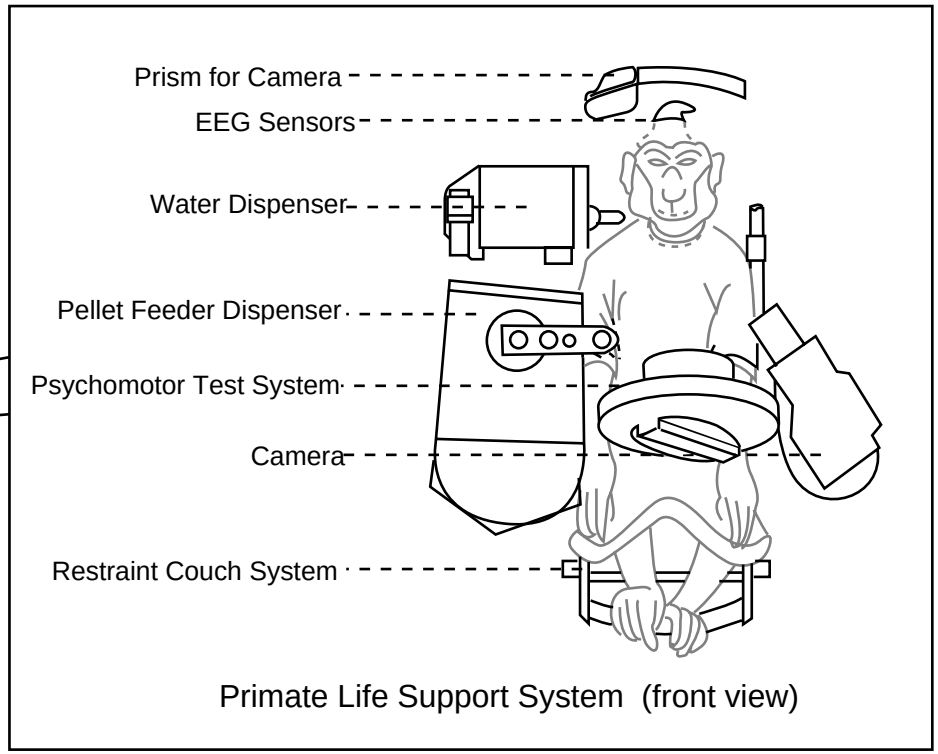
Publications

- *Biosatellite Project Historical Summary Report.* NASA-Ames Research Center. J.W. Dyer, ed. December 1969.
- Adey, W.R. et al.: Biosatellite III: Preliminary Findings. *Science.* Vol. 166: 492-493. October, 1969.
- Adey, W.R. and P.M. Hahn: Introduction-Biosatellite III Results. *Aerospace Medicine.* Vol. 42: 273-280. March, 1971.





Symbols Displayed for the Dlayed Matching Task are O, X, △□



Primate Life Support System (front view)

Missions Flown Through 1990: **Biosatellite III (p. 53)**

Race Tube Packages

Hardware Description

Race tube packages support studies of the pink bread mold, *Neurospora crassa*. For the experiment on STS-32, race tubes are configured into three packages, all contained within a single middeck locker. Each package opens at one end and contains five foam trays containing the race tubes, gas sampling syringes, and marking pens. Packages and package trays are constructed of flight foam and include two light-tight baffles for separating packages. Data collected during the mission include growth front markings and gas sampling.

Race Tubes: The race tubes are constructed with shrink tubing on the bent ends of the tubes (to prevent light piping) and are autoclaved. Preparation of race tubes include activities such as preparing labels, etching race tubes, and preparing media salts to be combined with agar. Tubes, as well as the gas sampling syringes, are wrapped with Scotch 800 tape to stregnthen the tubes and provide a surface for pen markings. The agar media is prepared from Vogel's salts, an acetate medium and a non-ionized detergent, and autoclaved. The media is poured into the race tubes under a laminar flow hood to ensure sterility, and is allowed to harden for 48 hours. After 48 hours, the race tubes are inoculated with either CSP or BND strains of *Neurospora crassa*. The inoculum is allowed to grow in constant bright light for 36 hours. The first set of tubes is known as the Red Package, since these tubes are wrapped with the Wratten Gelatin Red filter material; 25 unfiltered tubes, a syringe and pen constitute the Blue Package. Red and Blue Packages are manipulated during the flight, and a control package (White Package) is untouched by the crew and contains ten unfiltered tubes.

Red Package: For the red package, fifteen filtered tubes, one gas syringe and one marking pen are assembled and placed in flight foam. This package is the first visible to crew and has five layers of three race tubes each that are completely wrapped with a red light filter material. This package serves as control for light effects, as the *Neurospora* organism is not affected by the filtered light. The first layer in the package contains the marking pen and one gas sampling syringe. The second and third layers each contain one gas sampling syringe, each marked to correspond to the race tube that is to be gas sampled. The gases inside the tube are sampled and analyzed postflight.

Blue Package: The second package contains twenty-five clear (no filter) race tubes, pen, and three syringes in the same arrangement as the Red Package. These tubes will serve as the light-exposed and moved controls. The tubes are gas sampled and marked identically to the tubes in Red Package. The baffle between the Blue and White is not touched, as there is no crew interaction with the White Package.

White Package: The package furthest inside the locker also contains an ambient temperature recorder (ATR). This package is never touched by the crew during flight; the ten tubes (five layers of two tubes) containing *Neurospora* serve as controls for those tubes that receive light and are moved, variables that affect the circadian rhythmicity of *Neurospora* growth.

Specifications

Dimensions: 9 in (tube body)
Weight: Various
Power: None

Data Acquisition

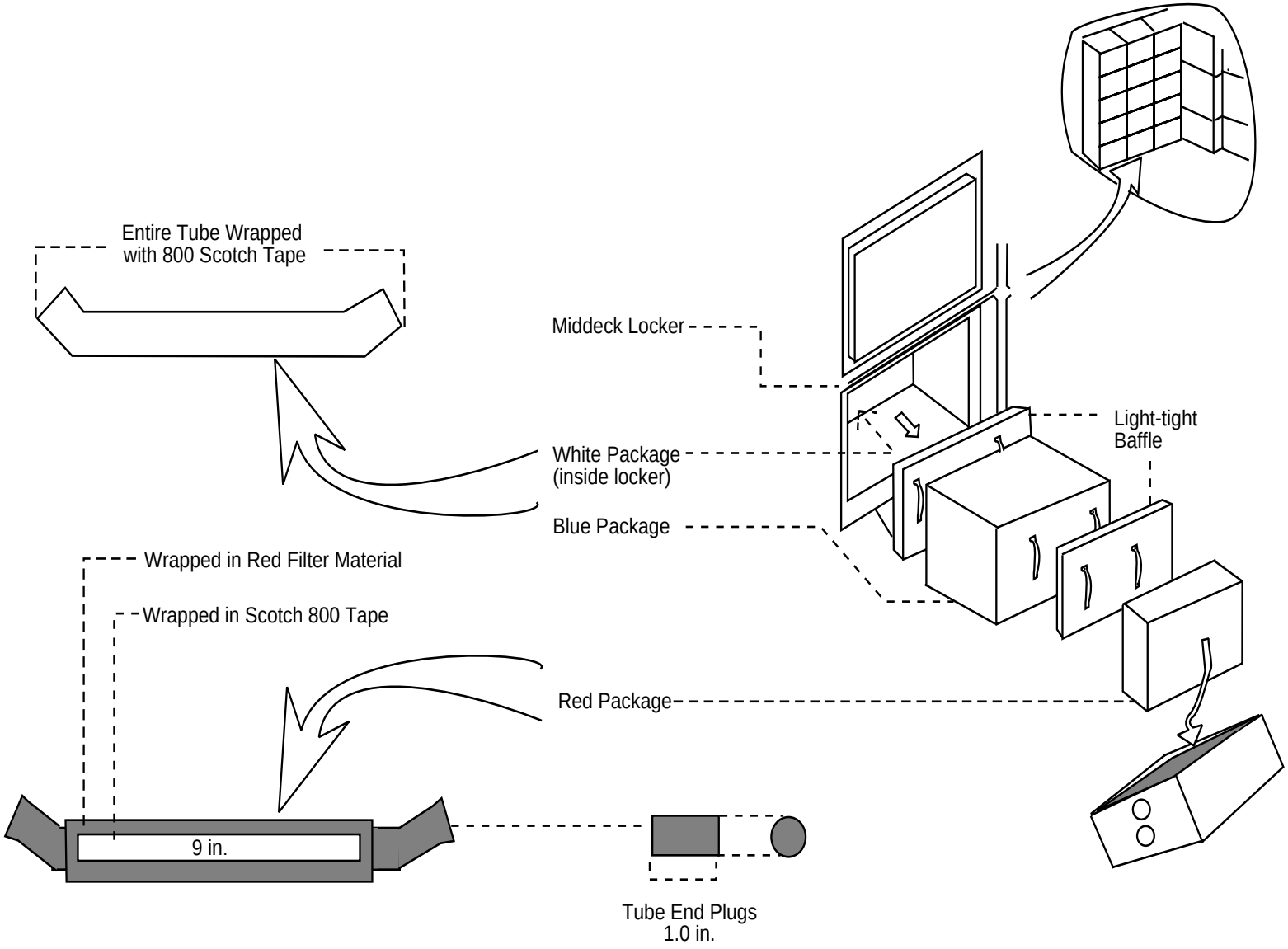
Gas sampling; crew markings of growth

Related Ground-Based Hardware

None

Publications

- Ferraro, James S.: Experiment Description: Characterization of Neurospora Circadian Rhythms in Space (CNCR) Secondary Payload-32. NASA-Ames Research Center, 1990.



Missions Flown Through 1990: **STS-32/CNCR (p. 99)**

Radiation Detectors: Plastic Nuclear Track Detectors (PNTD)

Hardware Description

Measurement of the high-LET (linear energy transfer) particle radiation is passively accomplished with plastic radiation detectors. Plastics used are cellulose nitrate (CN) and Lexan© polycarbonate. The minimum LET value that can be detected with these plastics is ~100 keV/µm Tissue. Plastic films used in detectors have a thickness of 100 µm (CN) and 250 µm (Lexan). The films are layered together in various combinations and placed about the interior of the spacecraft to measure the flux, integral LET spectrum and spatial distribution of HZE (high-energy ionized) particles.

Latent particle tracks in the plastics are developed by chemically etching the exposed films. In this process, the damaged region along the path of the particle is preferentially attacked by the etchant. The resulting track appears as a hole in the plastic film, whose size is determined by the duration of the development process.

Cosmos 782: On Cosmos 782, two different PNTD configurations were used to make measurements. Thin detectors consisting of seven layered thin plastic films, held together with tape, measured the flux and integral LET spectrum. Thin stacks measured 5 cm^2 and 0.15 cm thick. Aluminized mylar was wrapped around the stack to protect the plastics from any ultraviolet light exposure. A total of twelve detectors were placed on centrifuged and stationary containers housing U.S. carrot culture and Killifish development experiments. Thick detector stacks consisting of 75 layered plastic films measured the charge spectrum. The thick stacks were 9 cm^2 and 2 cm thick. Two thick detectors were placed on the stationary platform inside the biosatellite. Only PTND stacks were used for radiation measurements onboard Cosmos 782.

Cosmos 936: On Cosmos 936, PTND stack configurations were flown in conjunction with a variety of other radiation detectors (see *Cosmos 936 Radiation Detector Packets)*. Two films of each type of plastic were layered together and sealed, along with three nuclear emulsion films sealed in plastic, inside a black polyethylene envelope, to measure HZE flux, integral LET spectrum, and spatial distribution. The area of the plastic films was 4.5 x 6 cm. Eighteen detectors were located inside the U.S.-U.S.S.R. flight container: twelve detectors were attached in pairs to each of the six faces of a pyrel foam cube (7.7 cm^3) centrally located in the joint portion of the flight package; and six detectors were attached to the face of the U.S. package at one end the container. To measure the Z spectrum, a stack composed of 97 µm thick layers of CN and 188 µm thick layers of Lexan was located in the joint portion of the flight container; the layer sequence was ten layers of CN, 200 layers of Lexan, 65 layers of CN, 200 layers of Lexan, and ten layers of CN.

Other Cosmos Missions: On subsequent Cosmos missions (Cosmos 1129, 1887, and 2044), PNTD stacks were flown on both the interior and exterior of the biosatellite. The plastics used in these stacks differ with the experiment objectives and evolving dosimetry materials/techniques. See see *Cosmos 1129 Radiation Detector Packets*, and *Cosmos 2044* and *1887 Radiation Dosimeters* for more details.

Specifications

Dimensions: 100 µm (CN); 250 µm (Lexan)
Weight: Variable
Power: None

Data Acquisition

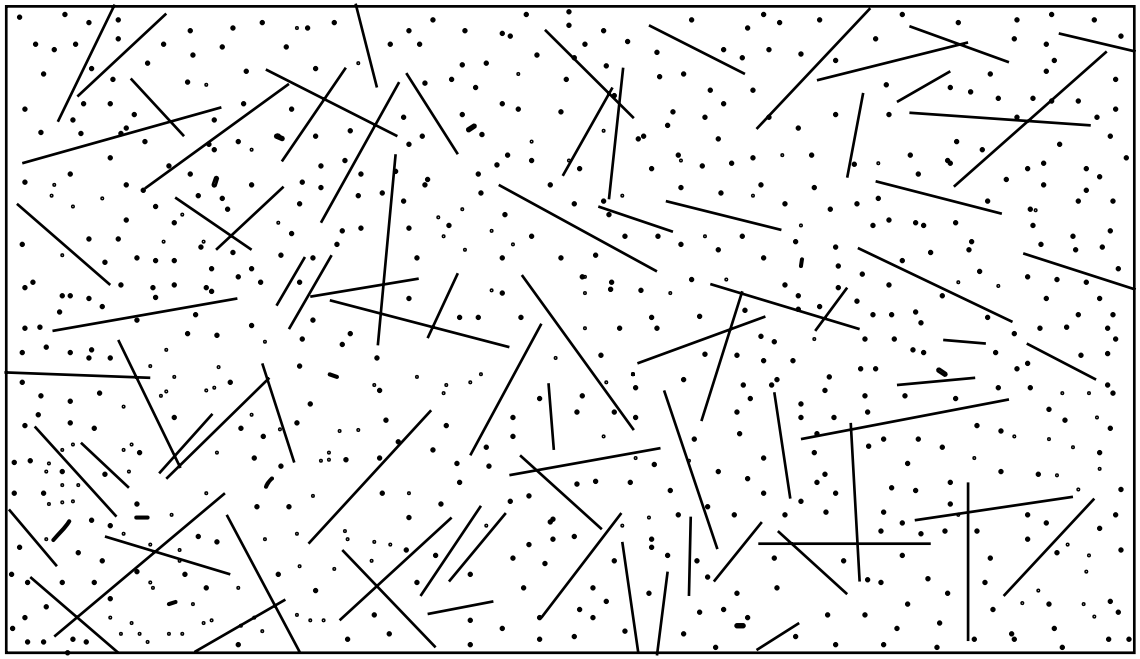
Radiation data

Related Ground-Based Hardware

High-Resolution Optical Microscope: Used to measure the depth and projection of the track in the plastic films. Track measurements are typically made at magnifications of 200-1,000x. Precision is in the order of ± 1µm.

Publications

- Peterson, D.D. et al.: HZE Particle Dosimetry. *Final Reports of U.S. Experiments Flown on the Soviet Satellite Cosmos 782.* NASA TM 78525: 160-178, 1978.
- Benton, E.V. et al.: Space Radiation Dosimetry on Board Cosmos 936. *Final Reports of U.S. Experiments Flown on the Soviet Satellite Cosmos 936.* NASA TM 78526: 184-245, 1978.



Positions of Measured Particle Tracks in the Cellulose Nitrate (CN)
Layer of the PNTD Stack Flown on Cosmos 936

Missions Flown Through 1990: **Cosmos 782 (p. 116), Cosmos 936 (p. 123), Cosmos 1129 (p. 128), Cosmos 1887 (p. 145), Cosmos 2044 (p. 150)**

Radiation Detectors: Cosmos 936 Radiation Detector Packets

Specifications

Dimensions: 48 x 127 x 13 cm (joint container)
Weight: Unknown
Power: None

Hardware Description

A joint U.S.-U.S.S.R. flight experiment package contains a number of U.S. radiation detectors designed mainly to determine physical parameters of different components of radiation in space. The joint flight experiment included the objective of elucidating results from Cosmos 782 which contained an unexplained difference in HZE flux values measured by American and Soviet investigators. The flight package consists of three separate parts: a U.S., 25% part which was located at one end of the experiment container; a U.S.S.R., 25% part located at the opposite end of the container; and a joint 50% part in the central region of the container. Detector materials from the 50%, joint portion are shared equally by U.S. and U.S.S.R. investigators.

Plastic Nuclear Track Detector (PNTD): Measurement of HZE (high-energy ionized) particle radiation is passively accomplished with plastic radiation detectors. PNTDs are located in the joint portion of the flight container and on the face of the U.S. detector package.

U.S. Detector Package: Several types of detectors are flown in the U.S. detector package in order to measure neutron fluxes present in the spacecraft. These are all passive integrating devices, employing either thermoluminescent detectors (TLDs) or track etch as the sensitive recording medium. In the first case, the high cross section of the $^{6}Li(n,T)^{4}He$ reaction in LiF TLDs is used. In the second, various radiator foils are sandwiched against cellulose nitrate (CN) plastic or moscovite mica which record the tracks of either ^{4}He particles or fission fragments, respectively.

Lithium Fluoride (LiF) Thermoluminescent Detector (TLD): The TLDs are of both ^{6}LiF and ^{7}Lif types. The chips are 0.635 cm square and 0.089 cm thick. The chips are composed of pure extruded LiF. Discrimination on the basis of the high neutron cross section of ^{6}Li can be made from the measurement differences between the two materials. Neutron measurements can be made in the presence of relatively large absorbed doses from other particles by this method.

Radiator Foil Detector Packet: Detectors having particle radiators composed of ^{6}Lif, ^{181}Ta, ^{209}Be, ^{232}Th, and ^{238}U are included in the packet. The first of these employs CN plastic to register the ^{4}He particles from the $^{6}Li(n,T)^{4}He$ reaction. The remainder contain mica to register fission fragments from the (n,f) reactions. The thickness of the ^{6}Lif radiator foils are 4.5 mg/cm^2. The thicknesses of the fission foils vary, but all are thicker than the ranges of the fission fragment produced. This gives the fission foil detectors maximum efficiency, since there is little attenuation of the detached neutrons through the foils. ^{6}Li detectors require a self-shielding correction.

Nuclear Emulsions: Measurement of the proton exposure component is accomplished by Ilford nuclear emulsions of the G.5 (25 µm and 50 µm) K.2 (100 µm) type. Each emulsion is mounted on a 178 µm Melinex substrate, and one of each type inserted into a 0.006 in thick black polyethylene bag, heat-sealed to ensure a light-tight container. Each such emulsion packet (3.8 x 5.1 cm) is then inserted, along with several plastic layers, into another black bag, forming a single "orthogonal" detector. Twelve U.S. packets were attached to the joint U.S.-U.S.S.R. foam cube and to the U.S. detector package.

Data Acquisition

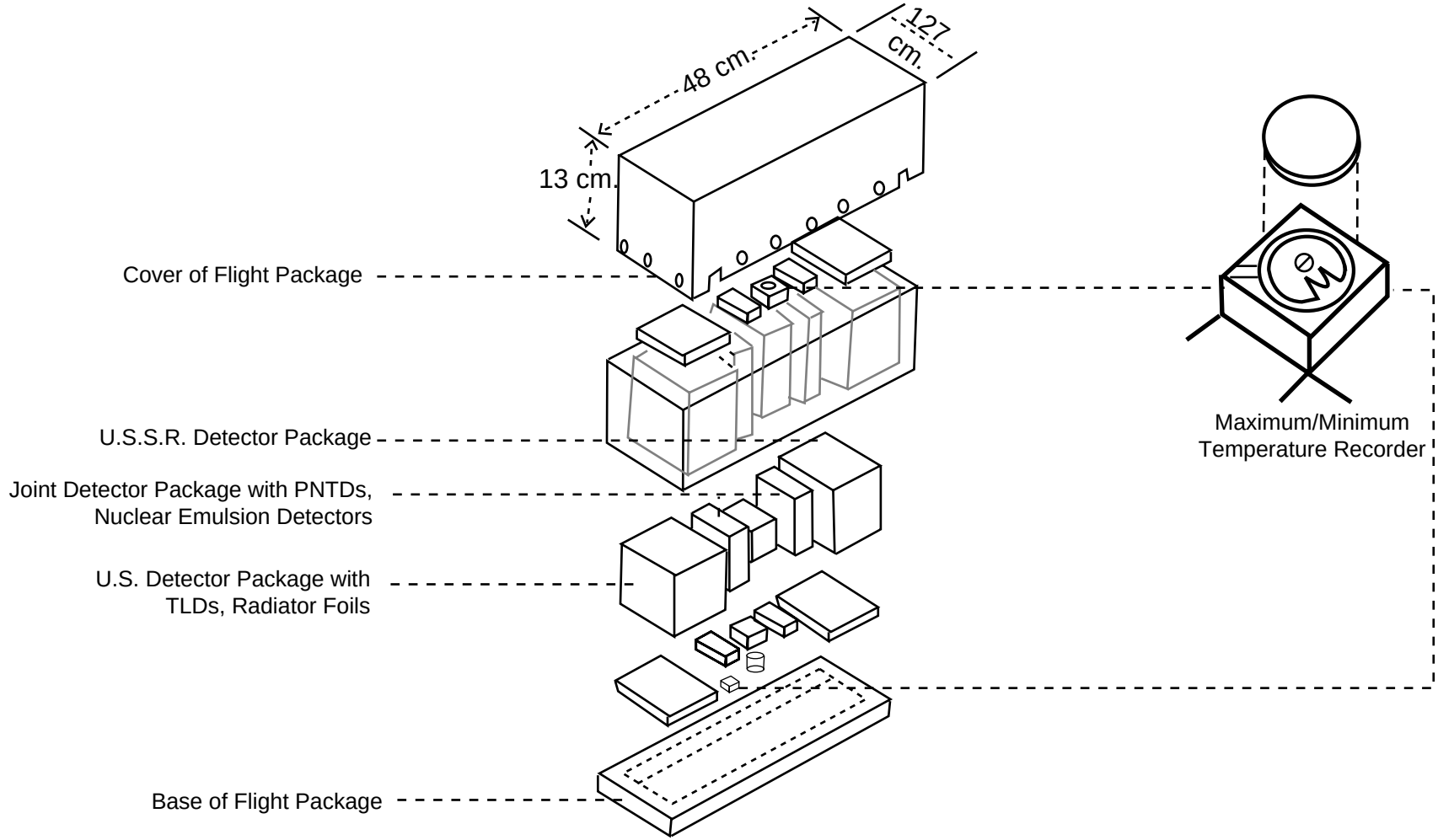
Radiation data

Related Ground-Based Hardware

TLD Reader: Heats TLD chips at a predetermined rate to a max of 250 °C, causing radiation-induced glow peaks to be emitted in proportion to the absorbed dose.
High-Resolution Optical Microscope: Used to scan radiator detector foils (~350x) for calculation of neutron fluxes and track densities, and nuclear emulsions (up to 1,000x) for determination of proton LET spectrum (>10 MeV), density and number.

Publications

- Benton, E.V. et al.: Space Radiation Dosimetry on Board Cosmos 936. *Final Reports of U.S. Experiments Flown on the Soviet Satellite Cosmos 936.* NASA TM 78526: 184-245, 1978.



Missions Flown Through 1990: **Cosmos 936 (p. 123)**

Radiation Detectors: Cosmos 1129 Radiation Detector Packets

Hardware Description

The detector packets include stacks of plastic nuclear track detectors (PNTDs) for measurements of high-LET (linear energy transfer) particles ($Z \geq 6$), and thermoluminescent detectors (TLDs) and radiator foil detectors for measurement of total doses due to charged particles and gamma rays.

Cosmos 1129 Corner Stacks: The corner stacks are designed to contain both TLDs, for measuring the total absorbed dose, and particle radiator detectors, for measuring the neutron fluences.

Interior Plastic Stacks: The PNTD stacks in the interior of the spacecraft consist of alternating layers of three different detector types. A single repeat contains four ordered layers of the plastic types: GE Lexan polycarbonate, American Acrylics CR-39, Lexan, and Kodak Pathe cellulose nitrate (CN); with respective nominal layer thicknesses of 190 µm, 1,000 µm, 190 µm, and 100 µm. This sequence is repeated a sufficient number of times to comprise the entire thickness of each of the stacks. The arrangement of the plastic stacks along the three orthogonal directions is the preferred configuration because of the somewhat anisotropic response of the detectors (they responded to lower LET particles at normal incidence than at grazing incidence).

Exterior Plastic Stacks: The exterior PNTD stacks consist of alternating layers of Lexan and CN sandwiched between the two layers of CR-39. These packages are maintained outside the spacecraft. One surface of each stack is exposed directly to the space environment except for a very thin evaporated layer of aluminum to reduce the UV exposure and temperature during the mission.

Exterior TLD Packets: The external TLD packets contain six TLD chips each of ^{7}LiF and CaF_2 for total absorbed dose measurements outside the hull of the spacecraft. The TLD chips are held in twelve square milled holes, 0.635 cm in dimensions, in an aluminum plate. The two TLD types are placed in alternate spaces and are spread, approximately equally, across the external packet dimension. An aluminum top plate, 0.318 cm thick, protects the TLDs from the external environment.

Specifications

Dimensions: Various
Weight: Various
Power: None

Data Acquisition

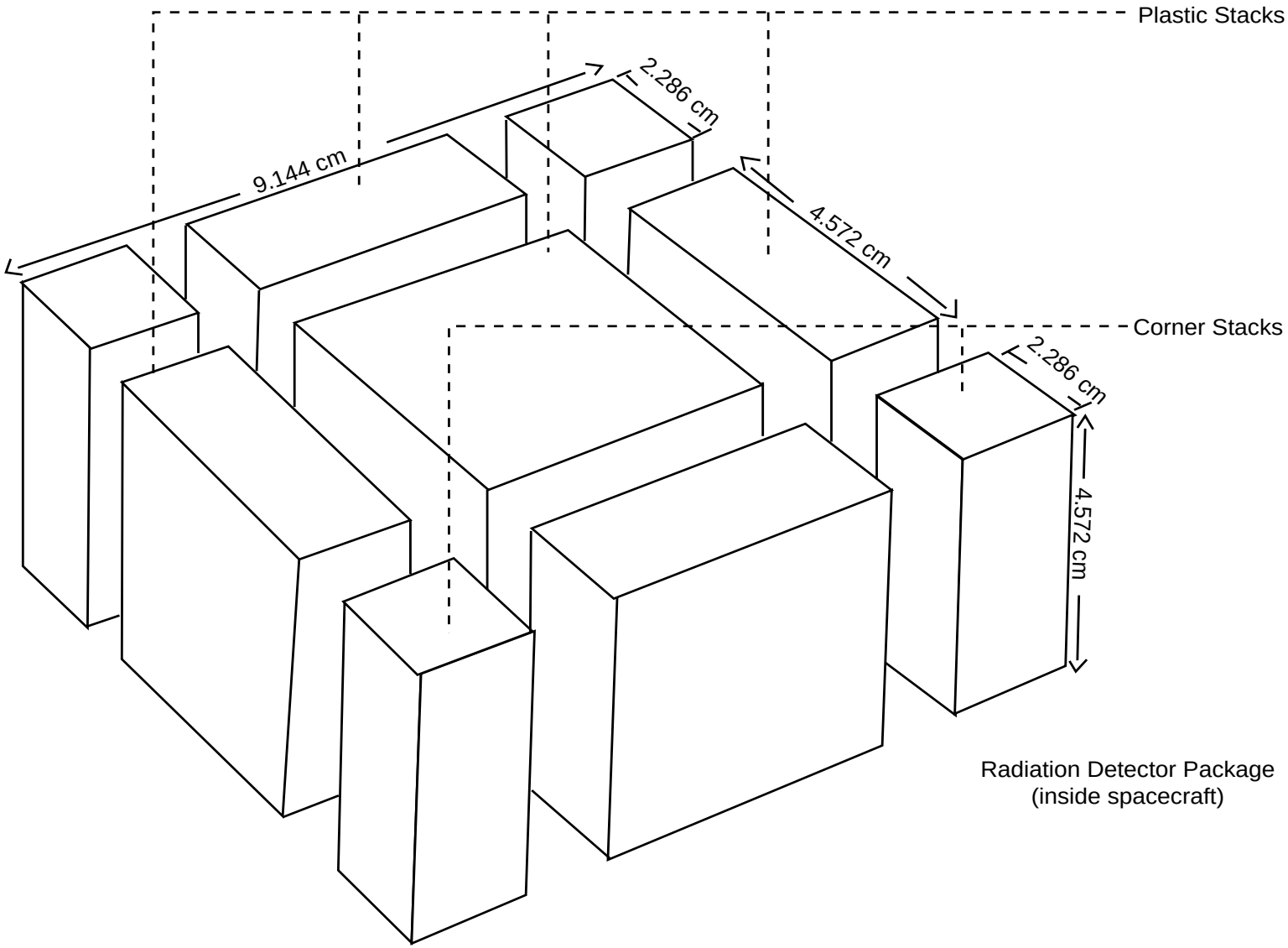
Radiation data

Related Ground-Based Hardware

High-Resolution Optical Microscope: Used to measure the depth and projection of the track in the plastic films. Track measurements are typically made at magnifications of 200-1,000x. Precision is on the order of ±1 µm.

Publications

- Benton, E.V. et al.: Space Radiation Dosimetry Aboard Cosmos 1129. *Final Reports of U.S. Plant and Radiation Dosimetry Experiments Flown on the Soviet Satellite Cosmos 1129.* NASA TM-81288: 123-188, 1981.



Missions Flown Through 1990: **Cosmos 1129 (p. 128)**

Radiation Detectors: Cosmos 1129 Corner Stacks

Hardware Description

Corner Stacks were flown in two different configurations on Cosmos 1129 as part of the U.S. radiation experiment. The stacks are designed to contain both thermoluminescent detectors (TLDs), for measuring the total absorbed dose, and particle radiator detectors, for measuring the neutron fluences. The TLDs used are TLD-700 (^{7}LiF) and TLD-200 (CaF_2). There are two types of particle radiators. Foils of ^{10}B and ^{6}LiF are used to produce ^{4}He particles by the (n, ^{4}He) reaction. Cellulose nitrate plastic is sandwiched against the radiator foils to record ^{4}He particle tracks. Fission foils of ^{209}Bi, ^{232}Th, ^{237}Np and ^{238}U are used to produce fission fragments by the (n,f) reaction. Muscovite mica is used to record the tracks of the emitted fission fragments.

Configuration I: The radioactive fission foils are separated from the TLDs to reduce the build-up of background gamma radiation doses in the TLDs. This results in two different configurations for the corner stacks. Stacks A and C hold the fission foil detectors plus those using ^{10}B foils. Stacks B and D hold the TLDs plus those detectors using the ^{6}LiF foils. Stacks A and C are composed of aluminum plates with alternate plates having milled holes of the proper sizes to contain the radiator detectors. Each stack contains two ^{10}B foils of 1.0 mg/cm^2 thickness and 1.27 cm diameter on a 1.588 cm diameter titanium backing. One of these foils is shielded by 1.0 mm thick plates of cadmium. Three foils each of ^{232}Th and ^{238}U, all of 1.27 cm diameter, are included. The ^{209}Bi foil is rectangular and 1.27 x 3.81 cm in dimensions. The three preceding foil types are unbacked and mica detectors are placed against both foil surfaces. Two ^{237}Np foils of 8 mg/cm^2 thickness and 1.27 cm diameter on a 1.588 cm diameter titanium backing complete the complement of foils.

Configuration II: Stacks B and D contain two foils each of ^{6}LiF, 4.5 mg/cm^2 in thickness and 1.588 cm in diameter, on a filter paper backing. One of these foils is shielded by 1.0 mm thick cadmium. The remainder of the corner stacks are devoted to the TLDs. Plates with two slots, milled to accept three TLD chips each of 0.635 by 0.635 cm dimensions, are placed near the tops and bottoms and at the centers of the stacks. Each plate contains three chips each of ^{7}LiF and CaF_2 TLDs.

Specifications

Dimensions: Various
Weight: Various
Power: None

Data Acquisition

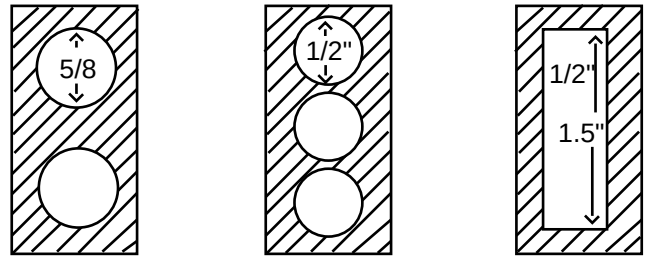
Radiation data

Related Ground-Based Hardware

TLD Reader: Employs a thirty-second read cycle and 10 °C/ second temperature ramp. Total glow peak distributions are recorded to a microcomputer, for glow peak deconvolution.

Publications

- Benton, E.V. et al.: Space Radiation Dosimetry Aboard Cosmos 1129. *Final Reports of U.S. Plant and Radiation Dosimetry Experiments Flown on the Soviet Satellite Cosmos 1129.* NASA TM-81288: 123-188, 1981.



Plates 1 & 5 Plates 2 & 3 Plate 4

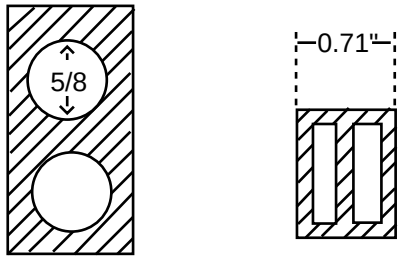
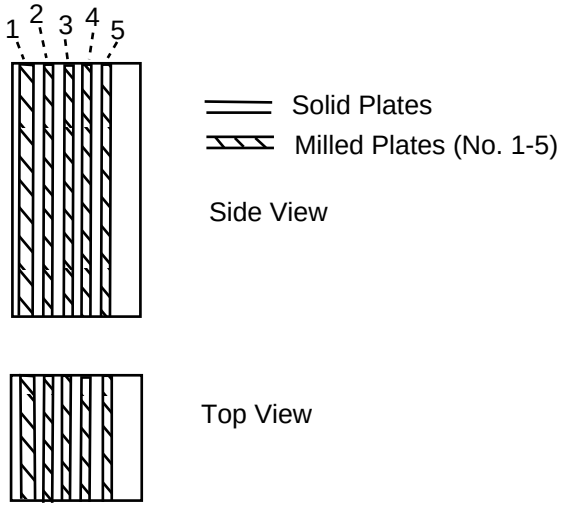
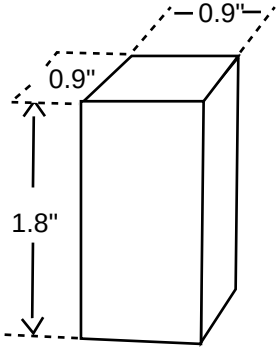
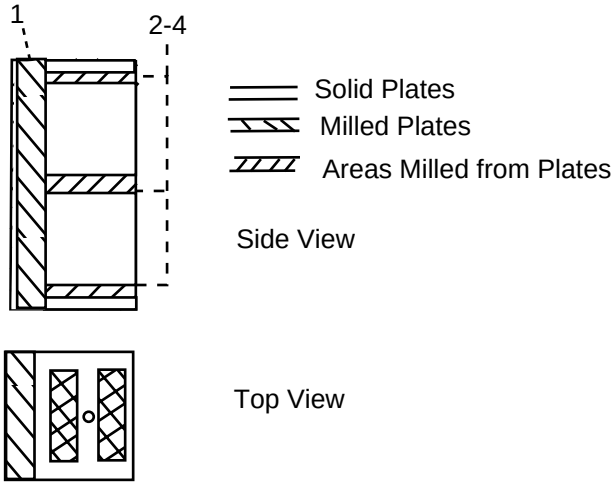


Plate 1 Plates 2-4







Configuration I		Configuration II	
Plate No. 1	=1/ 8 in	Plate No. 1	=1/8 in
Plate No. 2-5	=1/16 in	Plate No. 2-4	=1/16 in
Front Solid Plate	=1/16 in	Front Solid Plate	=1/16 in
Separation Plates	=1/16 in	Top/Bottom Plates	=1/16 in
Back Solid Plate	=0.210 in		

Missions Flown Through 1990: **Cosmos 1129 (p. 128)**

Radiation Detectors: Cosmos 1887 Radiation Dosimeters

Hardware Description

A set of radiation dosimetry and spectrometry measurements were conducted using passive detector systems located inside and outside the Cosmos 1887 spacecraft. Various versions of the different components of these systems are flown in different arrangements on other Cosmos missions (see *Cosmos 936 and 1129 Radiation Detector Packets*, and *Cosmos 2044 Radiation Dosimeters* for more details). All detectors for outside the spacecraft were held in a "clamshell"-style container which was closed before re-entry to prevent heating of detectors in the atmosphere.

Lexan Box Detector Assembly (LBDA): The assembly contains Plastic Nuclear Track Detector (PNTD) stacks, a set of thermoluminescent detectors (TLDs) and a nuclear emulsion stack. The components are placed in a Lexan polycarbonate plastic box, with the five PTNDs (one thick center stack, 2.255 in^2, plus four thin side stacks, 1.320 x 2.255 in) arranged in an orthogonal array to compensate for the angular response of PTNDs. The PTNDs used were special, high-sensitivity CR-39, plus several sheets of Tuffak polycarbonate detector. Heavy particle LET (linear energy transfer) spectrum is measured with the PNTD stacks. Emulsions are included for high-energy proton flux measurements.

Thermoluminescent Detector Assembly (TDA): Two identical flight units each containing two thin stacks and one thick stack of TLDs are used to measure depth doses (total absorbed dose) outside the spacecraft. The flight unit consisted of an aluminum cylinder of 5 cm diameter and 1.99 cm thickness with cylindrical holes to accommodate TLD stacks. An aluminized double- window of Kapton plastic totaling 15 µm serves to hold in the stacks and protects them from direct sunlight, heat, and vibration. In thin stacks, thirty thin TLD chips (9.14×10^{-3} cm) are placed at the tops, and twelve thicker (0.889 cm) TLD chips at the bottoms. For the thick stacks, sixteen of the thicker TLD chips are stacked. All TLDs are ^{7}Lif and separated by 15 µm thick polycarbonate film. Strips of stiff, 0.015 cm thick paper is placed beneath all stacks and on the sides (4) of the thick stacks for protection against vibration and movement.

Sealed Plastic Stacks (SPS): The stacks measure heavy particle LET spectra as a function of shielding depth in plastic outside the spacecraft. Doses and dose equivalents are also generated for the heavy particles. Hardware consists of two hermetically sealed flight units containing PTND stacks with aluminized Kapton double-windows, as above. PTND stacks are 3 cm in diameter and 1.4 cm thick and include sets of CR-39, Tuffak polycarbonate, and Cronar polyester detectors.

Outside Activation Foil Assembly (OAFA): The outside foil assembly measures neutron fluences outside the spacecraft. The two flight units contain ^{59}Co activation foils and PNTD films. An aluminum frame with aluminized Kapton double-windows is placed above the detectors, while the sides of the units were left open to vacuum. PNTDs of Tuffak polycarbonate and Cronar polyester are used for an intercomparison between those open to vacuum and those hermetically sealed (SPS, above). Due to space limitations, the CR-39 plastic is not included in these stacks.

Inside Activation Foil Assembly (IAFA): The inside foil assembly uses a single ^{59}Co activation foil to measure neutron fluences inside the spacecraft. The assembly is placed near the LBDA.

Specifications

Dimensions: 7 x 7 x 4 cm (LBDA)
Weight: 233 g (LBDA)
Power: None
Dimensions: 2 x 5 cm diameter (TDA)
Weight: 106.7 g (TDA)
Dimensions: 1.91 x 5 cm diameter (SPS)
Weight: 91.89 g (SPS)
Dimensions: 5.1 x 5.1 x 1 cm (OAFA)
Weight: 165.4 g (OAFA)
Dimensions: 5.1 x 5.1 x .65 cm (IAFA)
Weight: 145.5 g (IAFA)

Data Acquisition

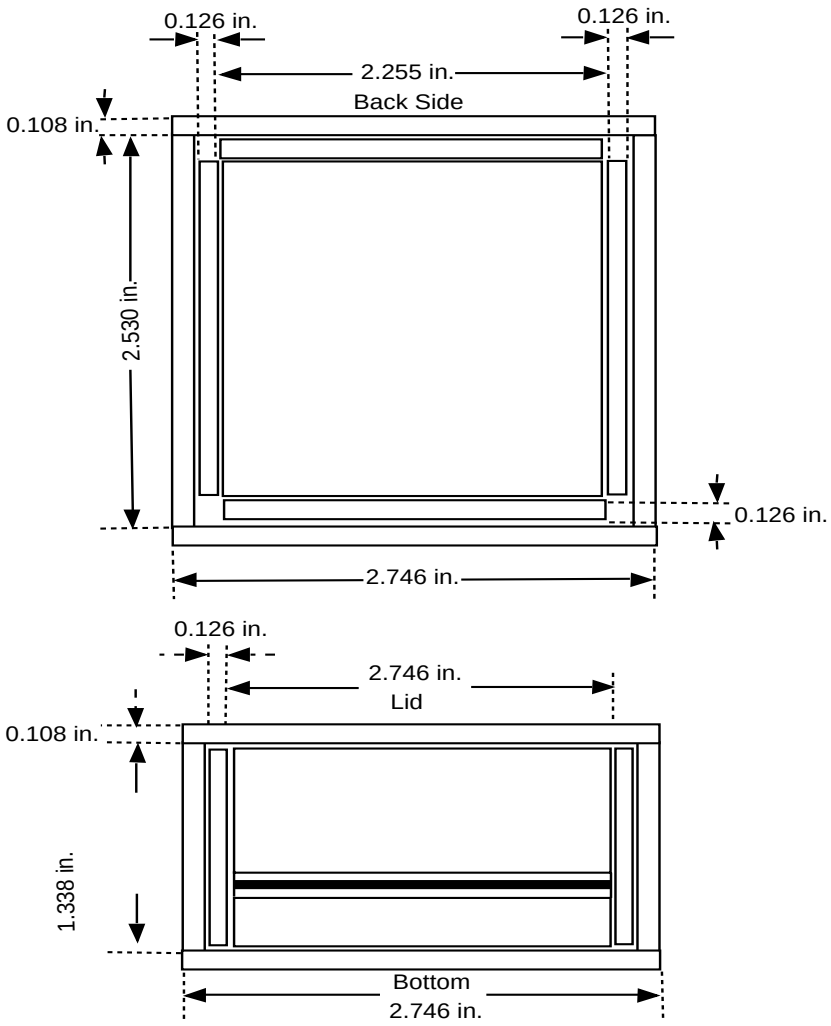
Spacecraft internal and external radiation data

Related Ground-Based Hardware

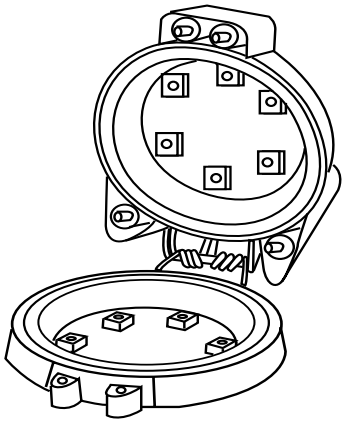
High-Resolution Optical Microscope: Used to scan nuclear emulsions, and polyester, polycarbonate and CR-39 PTNDs with pairs of CR-39 films in flight configurations for determination of short- and long-range tracks.
TLD Reader: Employs a 30-sec read cycle and 10 °C/sec temperature ramp. Total glow peak distributions are recorded on a microcomputer, for glow peak deconvolution.
Spectrometer: With a high-sensitivity, very low background gamma ray, used to scan ^{59}Co foils.

Publications

- Benton, E.V., et al.: Radiation Dosimetry and Spectrometry. *Final Report of the U.S. Experiments Flown on the Soviet Biosatellite Cosmos 1887.* NASA TM-102254, 1990, pp. 483–512.



Lexan box detector assembly (LBDA) contains plastic nuclear track detectors (PTNDs), theroluminsescent detectors (TLDs), and nuclear emulsion detectors.



Clamshell style container includes sealed plastic stacks (SPSS) and an outside activation foil assembly (OAFA).

Missions Flown Through 1990:Cosmos 1887 (p. 156)

Radiation Detectors: Cosmos 2044 Radiation Dosimeters

Hardware Description

A set of radiation dosimetry and spectrometry measurements were conducted using passive detector systems located inside and outside the Cosmos 2044 spacecraft. Various versions of the different components of these systems were flown in different arrangements on other Cosmos missions (see *Cosmos 936 and 1129 Radiation Detector Packets*, and *Cosmos 1887 Radiation Dosimeters* for more details). All detectors for outside the spacecraft were mounted on aluminum plates and held in "clamshell"-style containers which were opened after reaching orbit and closed before re-entry to prevent heating of detectors in the atmosphere.

Thermoluminescent Detector Assembly (TDA): TDAs are designed to measure the depth dose under very thin shielding and help determine what fraction of the dose was due to low energy electrons versus heavy charged particles. A total of twelve thermoluminescent detector (TLD) stacks are attached to the outside of the spacecraft. Each stack was composed of both thin (0.02395 g/cm^{-2}) and thick (0.2322 g/cm^{-2}) TLD extruded chips. Thin TLDs are used to a depth of 0.5175 g/cm^{-2}, and thick TLDs at greater depths. A double-window of 7.5 µm thick Kapton poly- imide films, both aluminized to an optical density of three, shield the TLDs from sun and space.

Sealed Plastic Stacks (SPS): Two hermetically sealed flight units containing plastic nuclear track detector (PNTD) and nuclear emulsion stacks measure the low energy, heavy particle (excluding electrons) LET (linear energy transfer) spectra under very thin shielding, as a function of depth. PTND stacks are 3 cm in diameter and include sets of CR-39 and Cronar polyester detectors. Emulsion stacks are enclosed with ATR-4 temperature probes in thin stainless steel cylinders of the same diameter. The units are placed outside the spacecraft.

Activation Foil Assembly (AFA): The outside foil assembly measures neutron fluences outside the spacecraft. The two flight units contain ^{59}Co activation foils and PNTD films. An aluminum frame with aluminized Kapton double-windows are placed above the detectors, while the sides of the units were left open to vacuum. PNTDs of Cronar polyester allow comparison between those open to vacuum and those hermetically sealed (SPS, above). The inside foil assembly uses a single ^{59}Co activation foil to measure neutron fluences inside the spacecraft.

Fission Foil Assembly (FFA): Fission foils of ^{232}Th, in conjunction with solid state nuclear track detectors of muscovite mica, measure high energy (>1MeV) neutron fluxes and dose equivalent rates. Each of the two flight units are composed of four ^{232}Th fission foils with mica (1.27 cm diameter) in an aluminum and Lexan polycarbonate holder. The arrangement of the foils is mica/^{232}Th/mica, with lead discs of 0.5 mm thickness placed on each side for reduction of radiation from the ^{232}Th foils. The units are placed outside the spacecraft.

Neutron Detector Assembly (NDA): Layers of ^{6}LiF-TLDs in conjunction with CR-39 PNTDs measure the thermal (<0.2 eV) and resonance (0.2eV<En<1 MeV) neutron fluxes and dose equivalent rates. Each of the two flight units is composed of two ^{6}LiF layers with CR-39 (1.27 cm square) in an aluminum, polycarbonate holder. The arrangement of components is CR-39/^{6}LiF/CR-39, with Gd foil of 0.0025 cm thickness around one of the detectors to absorb thermal neutrons and allow separation of thermal and resonance neutrons.

Specifications

Dimensions: 1.0 x 1.5 cm diameter (TDA)
Weight: 2 g (TDA)
Power: None
Dimensions: 1.91 x 5 cm diameter (SPS)
Weight: 92 g (SPS)
Dimensions: 5.1 x 5.1 x 1 cm (AFA)
Weight: 165 g (AFA)
Dimensions: 3.5 x 3.5 x 0.54 cm (FFA)
Weight: 13 g (FFA)
Dimensions: 3.8 x 1.9 x 0.54 cm (NDA)
Weight: 8 g (NDA)

Data Acquisition

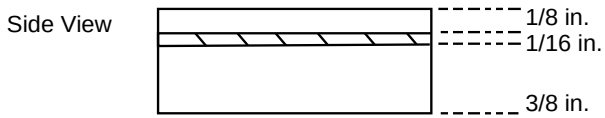
Spacecraft internal and external radiation data

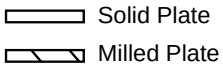
Related Ground-Based Hardware

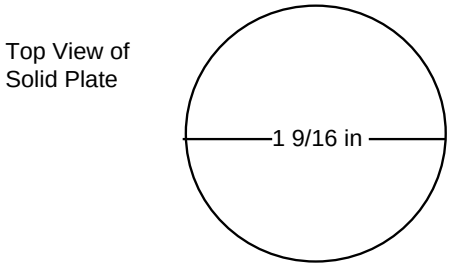
High-Resolution Optical Microscope: Used to scan nuclear emulsions, and polyester, polycarbonate and CR-39 PTNDs with pairs of CR-39 films in flight configurations for determination of short- and long-range tracks.
TLD Reader: Employs a thirty-second read cycle and 10 °C/sec temperature ramp. Total glow peak distributions are recorded on a microcomputer, for glow peak deconvolution.
Spectrometer: With a high-sensitivity, very low background gamma ray is used to scan ^{59}Co foils.

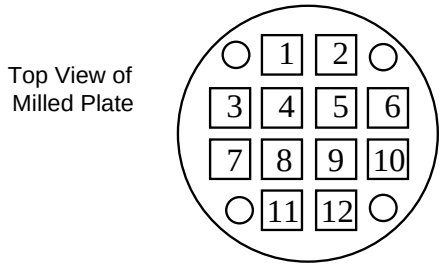
Publications

- Benton, E.V., et al.: Radiation Experiments on Cosmos 2044. *Final Reports of U.S. Experiments Flown on the Soviet Biosatellite Cosmos 2044, vol. 2.* J.P. Connolly, R.E. Grindeland, and R.W. Ballard, eds., NASA TM-108802, September 1994, pp. 387–424.





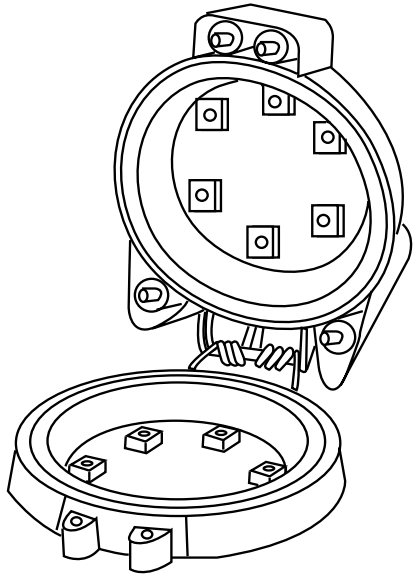




Thermoluminescent detectors (TLDs) are assembled in units of 12 to form the thermoluminescent detector assembly (TDA)

Li^7 F TLDs are in 1, 3, 5, 8, 10, and 12.

CaF_2 TLDs are in 2, 4, 6, 7, 9, and 11.



Clamshellstyle container
includes TDAs, sealed plastic stacks (SPSs), an activation foil assembly (AFA), and a fission foil assembly (FFA).

Missions Flown Through 1990:Cosmos 2044 (p. 162)

Radiation Source and Holder

Hardware Description

The Radiation Source Capsule and Holder are designed to expose biological objects to a controlled amount of radiation inflight.

Radiation Source Capsule: The radioactive element, ^{85}Sr powder, is poured into a stainless steel capsule. Radioactive ^{85}Sr is produced by irradiation enriched ^{84}Sr $(NO_3)_2$ with neutrons. The resulting powder is then poured into a stainless steel capsule. The powder is retained within the capsule volume by welding the base plug in place. Only the portion above the plug contains the powder. After loading with powder, the radiation source capsule is then inserted into the Radiation Source Holder.

Radiation Source Holder: The purpose of the radiation source holder is to shield the radiation source before and after the exposure period and shield the control experimental packages in the aft section of the Biosatellite capsule. It consists of an approximately hemispheric mass of sintered tungsten and associated drive mechanism. A wheel is mounted in the holder. A small section of the wheel projects above the top surface of the holder. When the wheel turns, the source is retracted and the intensity at the surface of the holder will not exceed 40 mr/hour. The drive mechanism, which rotates the source through the closed-open-closed cycle, is spring-driven with a solenoid-controlled latch mechanism. As a backup safety measure, the holder is designed to rotate to the safety position under the action of re-entry g forces, if the close command is not received.

Specifications

Dimensions: 0.5 in (diameter) x .805 in
Weight: 32 lbs (Source Holder)
Power: None

Data Acquisition

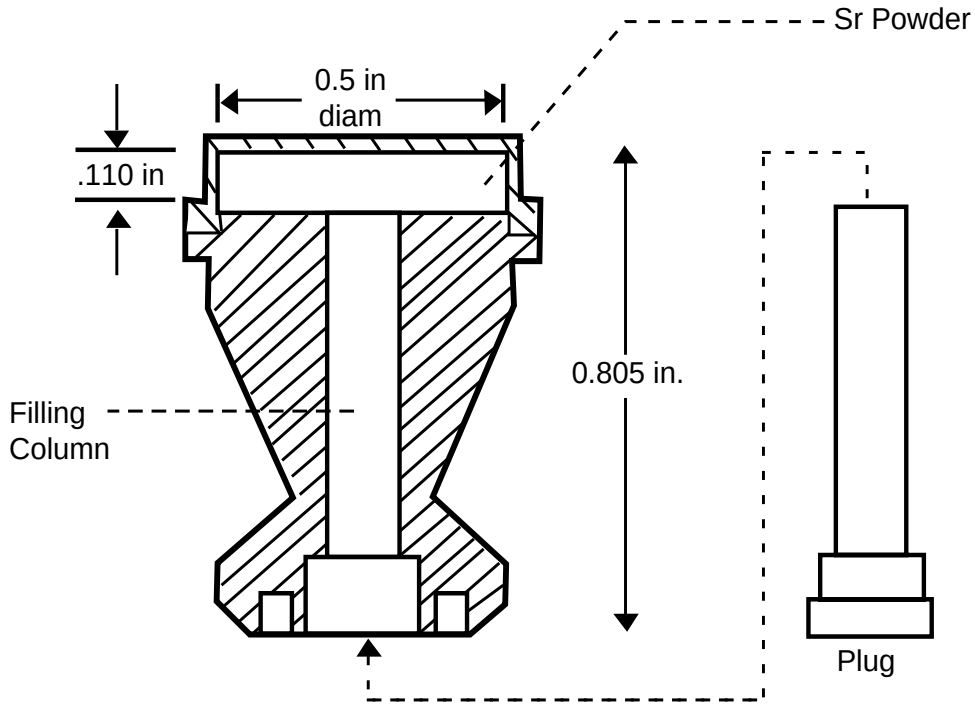
None

Related Ground-Based Hardware

None

Publications

- Hewitt, J.E.: Radiation Exposures During the Biosatellite II Flight. *Bioscience*, vol. 18, no. 6, June 1968, pp. 565–569.
- *Biosatellite Project Historical Summary Report.* J.W. Dyer, ed., NASA TM-X-72394, December 1969.



Radiation Source Capsule

Missions Flown Through 1990:Biosatellite I/II (p. 46)

Rana (Frog) Experiment Package

Hardware Description

The Rana (frog) experiment package consists of acrylic modules. Each module is divided into two chambers: 1) a 10 cc egg chamber and 2) a 4 cc fixative chamber. The O-ring-fitted piston separating the chambers is spring-loaded and actuated in module pairs, by preprogramming or by command. The actuation results in a forceful mixing of fixative and the egg medium.

For Biosatellite II, sixteen modules are inserted into a metal assembly which has external coils for the water-glycol coolant that maintains the experiment at 42.5 °F on the launch pad. Four thermistors attach to each of four modules in the packages and provide a temperature readout. A fifth thermistor serves as a sensor for switching off strip heaters which are to raise the package temperature from 43 to 70 °F immediately postlaunch. Thereafter, experiment temperature control is dependent on ambient spacecraft temperature. Fertilized eggs were placed in groups of ten in each of the first eight modules to be actuated, and in groups of five in each of the remaining. Each one of the modules of a pair received the eggs from one of two donor frogs. The glutaraldehyde fixative, in osmotically conditioned (sucrose) Sorensen phosphate buffer, yielded after mixing a final concentration of 2.5% glutaraldehyde.

Earlier versions of this hardware were used in frog egg experiments conducted on the Gemini-8 and Gemini-12 missions. These earlier packages have four chambers each, each chamber is capable of containing five frog eggs, for a total of twenty. A partitioned section within each chamber contains a concentration of formalin, which when injected into the egg chamber gave a 0.5% concentration of formalin. Packages are insulated and contain a temperature control system to maintain a temperature of 21 ± 0.5 °C, and electrical power is obtained from the spacecraft. The fixative injections are actuated by two handles on the outside of the package. The major innovation for Biosatellite I/II was the development of a treatment to detoxify the hardware plastics, principally outgassing by vacuum exposure, as well as a configuration appropriate to the Biosatellite environment, utilizing six times as many eggs.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: Unknown

Data Acquisition

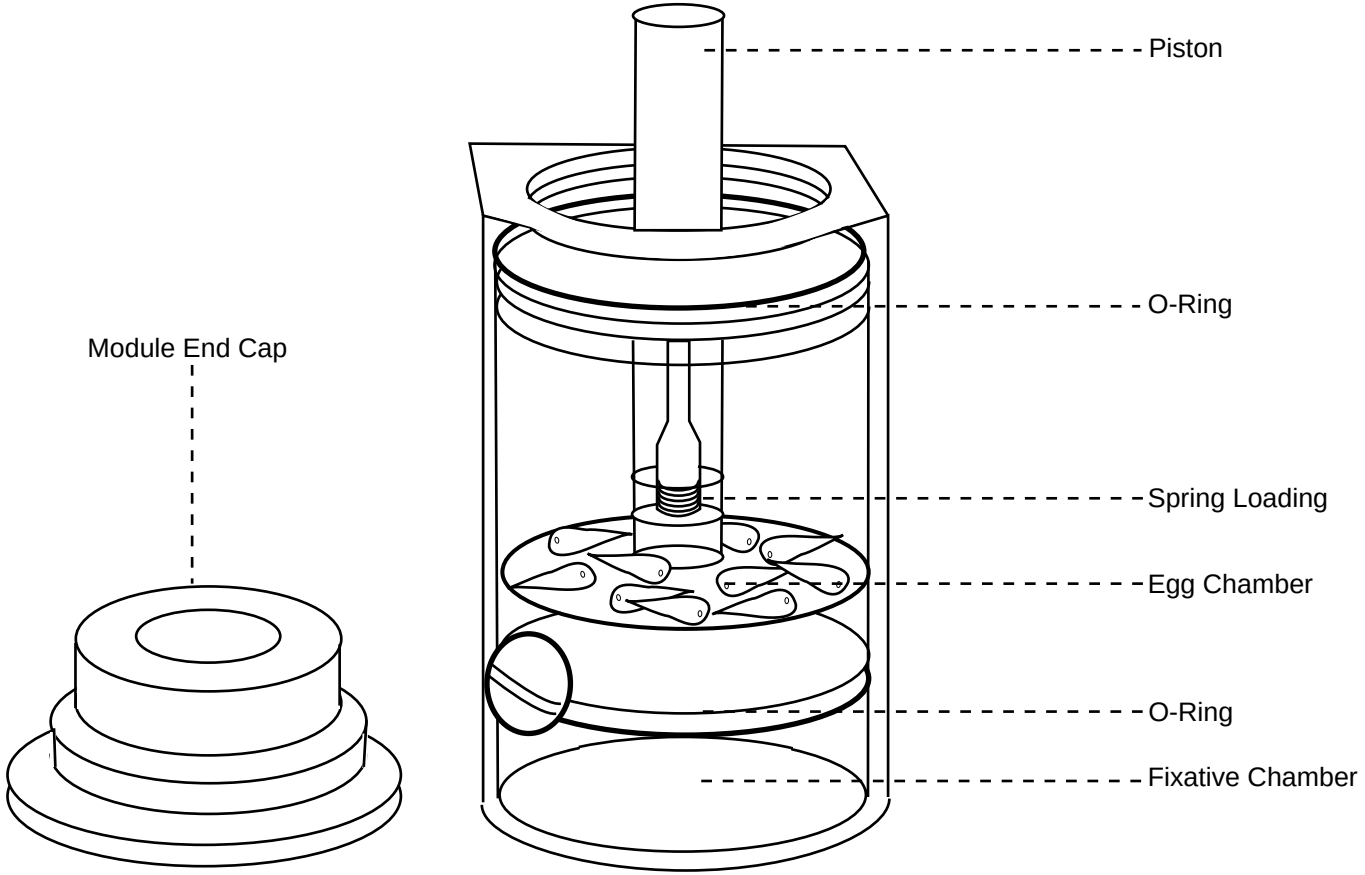
Radiation and temperature data

Related Ground-Based Hardware

None

Publications

- Young, R.S. and J.W. Tremor: Session III—The Effect of Weightlessness on the Dividing Egg of Rana pipiens. *Bioscience*, vol. 18, no. 6, June 1968, 609–615.
- *Biosatellite Project Historical Summary Report.* J.W. Dyer, ed., NASA TM-X-72394, December 1969.
- Willoughby, R.: *Toxicity Problems in Plastic Hardware Designed for Biological Spaceflight Experiments.* NASA TM-X-1818, 1969.



Missions Flown Through 1990:Gemini VIII (p. 38), Gemini XII (p. 40), Biosatellite I/II (p. 46)

Hardware Description

The Research Animal Holding Facility (RAHF) is a general use, contained animal habitat within the STS Spacelab capable of holding up to 24 adult rats (350 gm) in pairs or four adult squirrel monkeys (1 kg) within separate cages. The monkey and rat versions of the RAHF differ only in the design of the cage module to accommodate different animal sizes; otherwise all subsystems are identical.

***Environmental Control System (ECS)*:** The ECS is mounted on the back of each cage module to circulate conditioned air through the cages to control temperature and humidity, and to remove CO_2 and replenish O_2 by exchange of air with the Spacelab.

***Feeding/Watering Systems*:** Rodent food bars and primate pellets are supplied automatically on an *ad libitum* basis. Individual water lixits are positioned within each rodent and primate cage and dispense water *ad libitum*.

***Primate Cage Modules*:** A squirrel primate cage module system supports four squirrel monkey cages.

***Rodent Cage Modules*:** A rodent cage module supports twelve cage inserts, each containing two rats, separated by an internal divider for a total of 24.

Activity Monitors: Each rodent and primate cage compartment contains activity monitors that record general animal movement (one for each rodent cage, two for each primate). It consists of an infrared light source (920 nm beam) and sensor mounted on the right side of the cage and reflector tape mounted on the left side of the cage. When the animal breaks the light beam and therefore the circuit, a counter is electronically advanced one pulse. The counter reading is recorded by the RAHF data system for transmission to the ground in realtime or near realtime.

Data System: The system collects three data types: 1) analog data (temperature, humidity, water pressure, air flow); 2) event or discrete data (heating, cooling, lighting, water leakage); and 3) pulse-code modulated data (food, water, activity). The data system collects selected data and sends it to the front panel of the RAHF to an umbilical for monitoring selected RAHF data prior to launch, and to a recorder during liftoff and landing; it formats data through a Remote Acquisition Unit (RAU) for processing by the onboard experiment computer utilizing a series of data display formats.

Lighting System: Cage illumination provides a day/night cycle capability. The baseline system uses two long-life, incandescent lamps for each rat cage and one per mouse cage (not yet flown). The lamps are located in the air plenum above the cages. Each lamp provides 2.1 lumens and approximately 5 foot candles of light at the cage floor. Each of six tiers of drawers can be independently controlled for lighting through a manual or timed operation. The timed operation is performed by selection and setting of "on" and "off" time dials on the front of the RAHF rack.

Specifications

Dimensions: Occupies 1.5 ESA racks

Weight: 280 kg (616 lb), total

Power: 324 W, continuous operation; 850 BTU/hour, maximum thermal load

Operation: 1 g or 0 g in horizontal or vertical position

Capacity: Rodents up to 350 g; primates up to 1,200 g

Data Acquisition

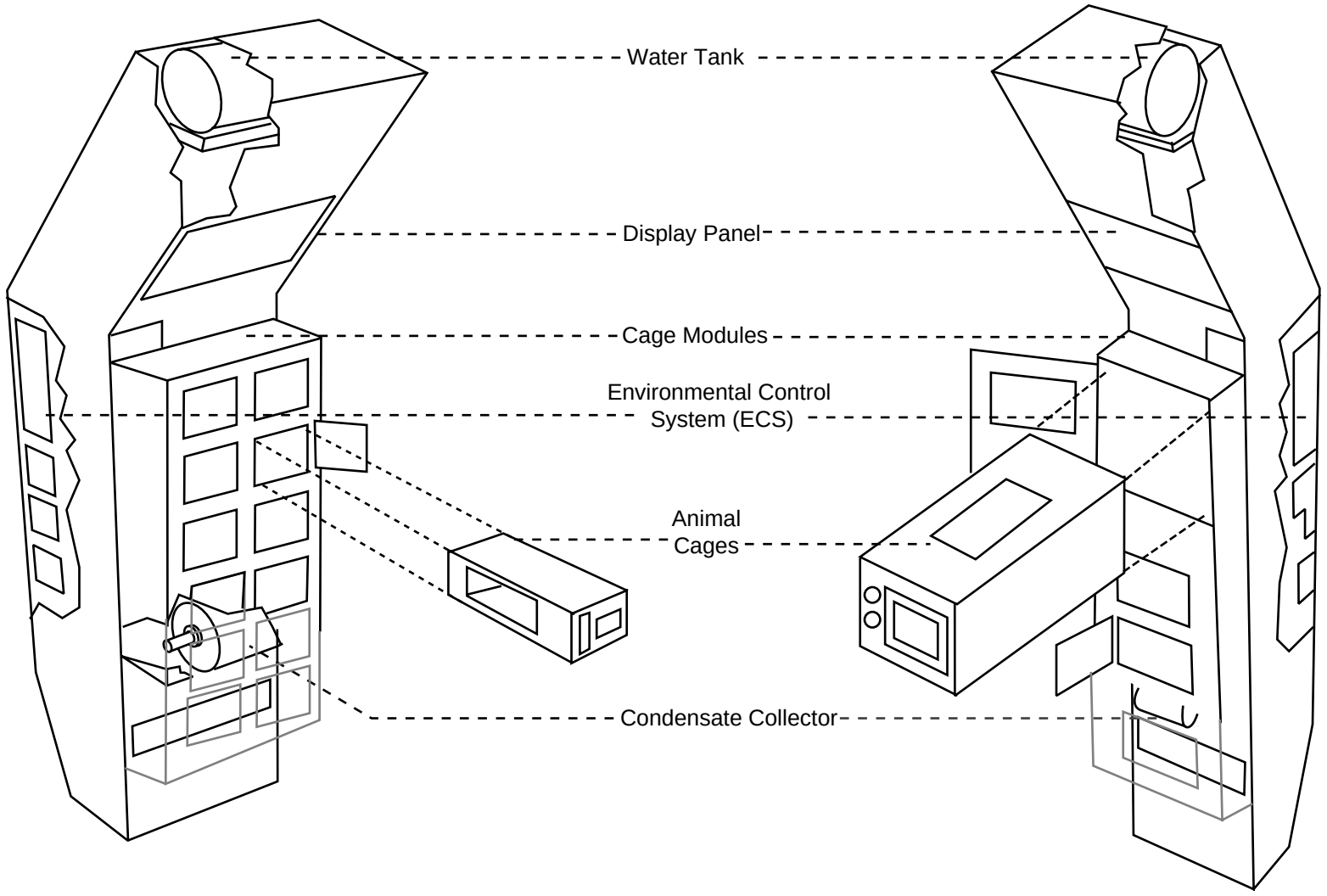
Food, water, and activity counts (digital); temperature, humidity, water pressure, and air flow (analog)

Related Ground-Based Hardware

None

Publications

- Callahan, P.X., et al.: Ames Research Center Life Sciences Payload Project for Spacelab Mission 3. *SAE Technical Paper Series 831094,* July 1983.
- Hogan, R.P. and B.P. Dalton: Performance of the Research Animal Holding Facility (RAHF) and General Purpose Work Station (GPWS) and other Hardware in the Microgravity Environment. *SAE Technical Paper Series 911567,* July 1991.
- *Ames Research Center, Life Sciences Payload, Spacelab-3, 60 Day Report*. P.X. Callahan, ed., NASA Ames Research Center, Space Life Sciences Payload Office, April 1985.



Missions Flown Through 1990:STS-51B/SL-3 (p. 92)

Research Animal Holding Facility (RAHF): Environmental Control System (ECS)

Hardware Description

The RAHF Environmental Control System (ECS) is mounted on the back of each cage module (rodent or primate) to circulate conditioned air through the cages. It provides basic life support functions of temperature and humidity control, and passive carbon dioxide removal and replenishment of oxygen by exchange of air with the Spacelab. Two propeller fans force cabin air through a filter into the RAHF; a portion of the circulating air within the RAHF is drawn through a filter and a charcoal bed which removes odors and particulate matter. These two filters bacteriologically isolate the animals and crewmen, and ensure that the RAHF maintains a slightly negative pressure with respect to the cabin. Air within the RAHF is circulated by a cluster of four propeller fans. A portion of the recirculated air is drawn through the cold side of the thermoelectric unit (TEU) for temperature control. The Spacelab experiment cooling loop provides the heat sink for the TEU. A hydrophilic coating on the TEU condenses water (for "humidity" control) by capillary action. Water, with some air, is sucked from the trailing edge of the aircore and pumped by a water separator into a condensate collector bottle, changed out by the crew as required. The cooled, dehumidified air is warmed, as necessary, by a heater, and is remixed with circulating air prior to return to the cages. An electronic system modulates cooling and heating to provide temperature control in the RAHF.

Specifications

Dimensions:	Unknown
Weight:	Unknown
Power:	Unknown
Temperature Range:	20 to 27 ± 1 °C
Humidity Range:	25 to 70%
Min O2 partial pressure:	0.21 bars
Max CO2 partial pressure:	0.008 bars
Cage Air Flow:	180 cfm at 9.2 m/min (30 ft/min)

Data Acquisition

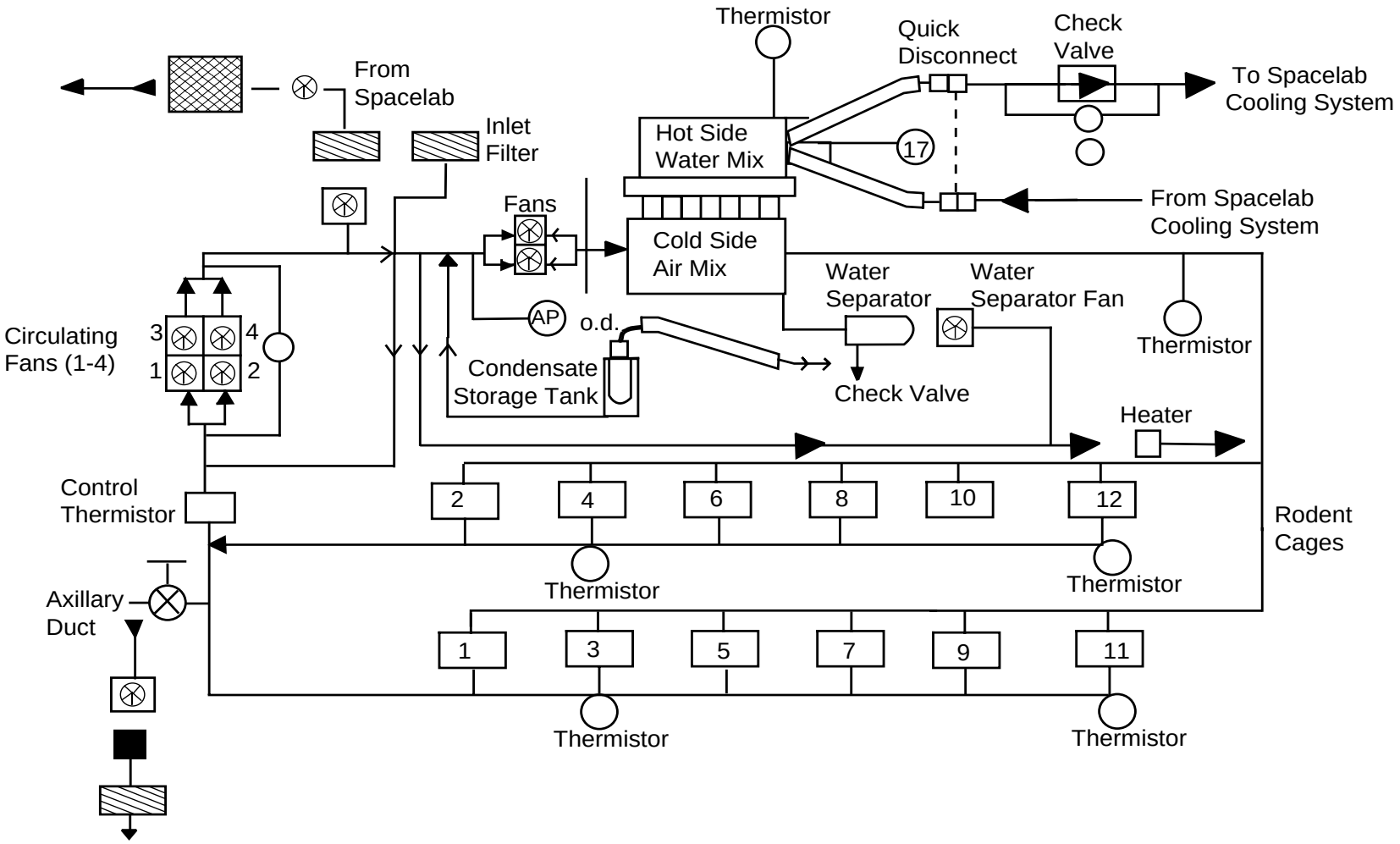
Temperature, humidity, and air flow (analog)

Related Ground-Based Hardware

None

Publications

- Callahan, P.X., et al.: Ames Research Center Life Sciences Payload Project for Spacelab Mission 3. *SAE Technical Paper Series 831094,* July 1983.
- Hogan, R.P. and B.P. Dalton: Performance of the Research Animal Holding Facility (RAHF) and General Purpose Work Station (GPWS) and other Hardware in the Microgravity Environment. *SAE Technical Paper Series 911567,* July 1991.
- *Ames Research Center, Life Sciences Payload, Spacelab-3, 60 Day Report*. P.X. Callahan, ed., NASA Ames Research Center, Space Life Sciences Payload Office, April 1985.



Missions Flown Through 1990:STS-51B/SL-3 (p. 92)

Research Animal Holding Facility (RAHF): Feeding/Watering Systems

Hardware Description

The feeding systems for the *Rodent Cage Modules* and for the *Primate Cage Modules* differed significantly, while both caging systems utilized the same watering system, which is incorporated into the overall RAHF design. Conversely, feeding systems are part of the cage modules, and food consumption is monitored by the RAHF data system.

Rodent Feeder: Rodent food is supplied *ad libitum* in the form of a compressed diet bar. In all missions, animals are adapted to the diet pre-flight and also provided the same diet during ground control studies. For Spacelab-3 the food bar diet was a rice base and the feeder mechanism was electromechanically monitored to provide an estimate of food counts/consumption. However, the original food bars crumbed during the SL-3 flight resulting in a loss of some consumption data.

The RAHF Rodent Feeder has been upgraded since first tested during SL-3. The feeder mechanism now operates so that each time the rat takes a bite of food, the food bar advances via a constant-force spring. The average food bar utilized in the current RAHF configuration is 350 g, contains approximately 25% water, and utilizes a wheat flour base relying on a gluten binding. Nominal rat consumption is 30 g per day, and manual crew changeout of each bar is required inflight. The removable feeder cassette contains two food bars (one servicing the forward cage, the other servicing the back cage) and expandable tape measures showing food bar length remaining.

Primate Feeder: The pellet feeder occupies one upper corner of the cage. The primates obtain a banana-flavored pellet from a dispenser when the animal taps a lever within the cage a set number of times. A relay is actuated whenever a pellet is dispensed from the feeder, and a pellet count is recorded on the RAHF data system. See *Primate Cage Modules* for a detailed description of the feeder.

Watering System: The RAHF *ad libitum* watering system consists of a pressurized bladder tank, pressure regulator, and a system of 24 sets of solenoids, pressure switches, and accumulators that measure increments of water to lixit valves for the animals, and water consumption counters. The self-pressurized bladder tank is located in the uppermost part of the RAHF. As the water is used up, a diaphragm collapses the bladder; the expansion of a pressurized gas in the remainder of the tank ensures water pressure in the absence of gravity. A pressure transducer on the tank side of the pressure regulator indicates the quantity of the water remaining in the tank. A filter downstream isolates the tank from animal bacteria.

For the rodents, a lixit provides a "water ball" which is replenished as the animal "tongues" the spigot. A count is registered each time a measured quantity of water leaves the lixit valve. Cage tops have holes large enough for an animal to activate the lixit watering valve located in the air plenum above. Placement of the lixits outside avoids disconnecting plumbing each time a cage is removed or installed. A similar watering system with the lixit protruding through the rear cage wall is available for primates, but their water acquisition also includes sucking behavior.

Specifications

Dimensions:	2.29 x 3 x 4.06 cm (rodent food bar)
Weight:	300 mg each (primate pellet)
Power:	Unknown
Food Bar:	Average 3-day supply
Water Capacity:	Inflight supply for up to 32 days
Watering Contingencies:	Warning of water lack or excessive consumption/leak

Data Acquisition

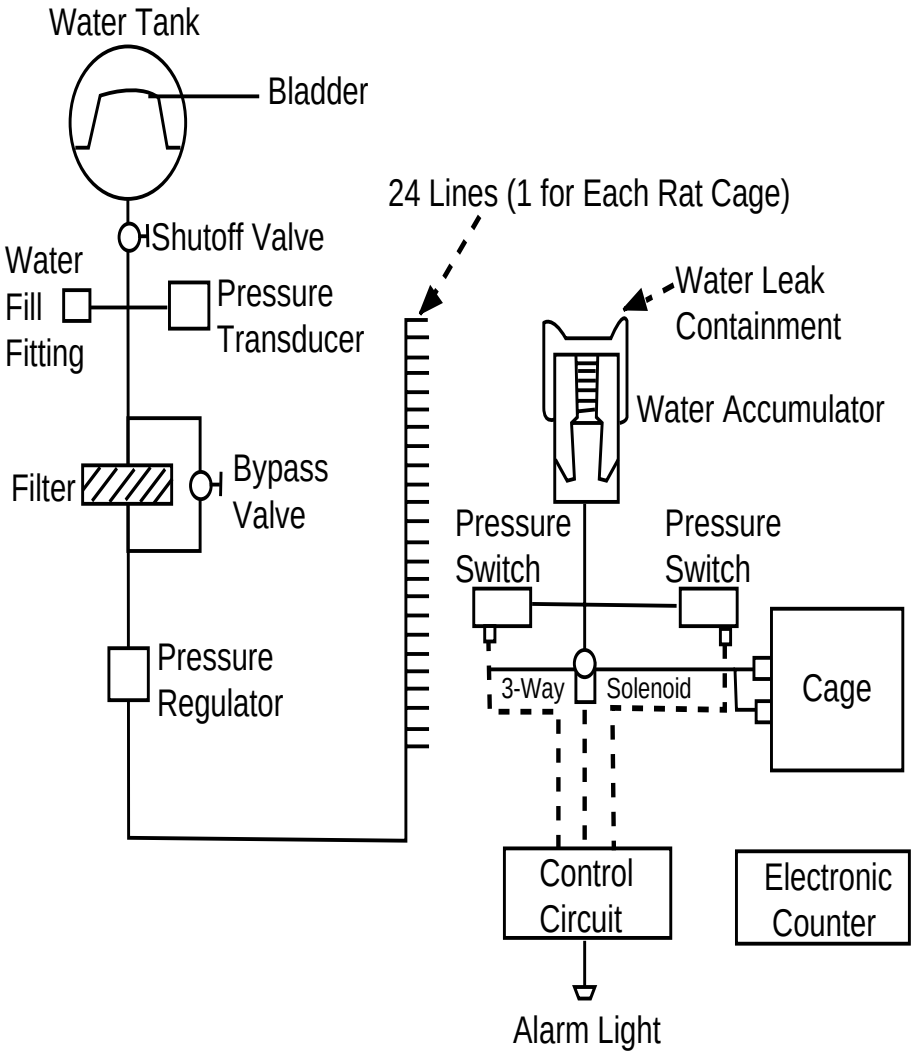
Food (prescribed amount of rodent bar, counts for primate pellets) and water (to an accuracy of 0.5 ml)

Related Ground-Based Hardware

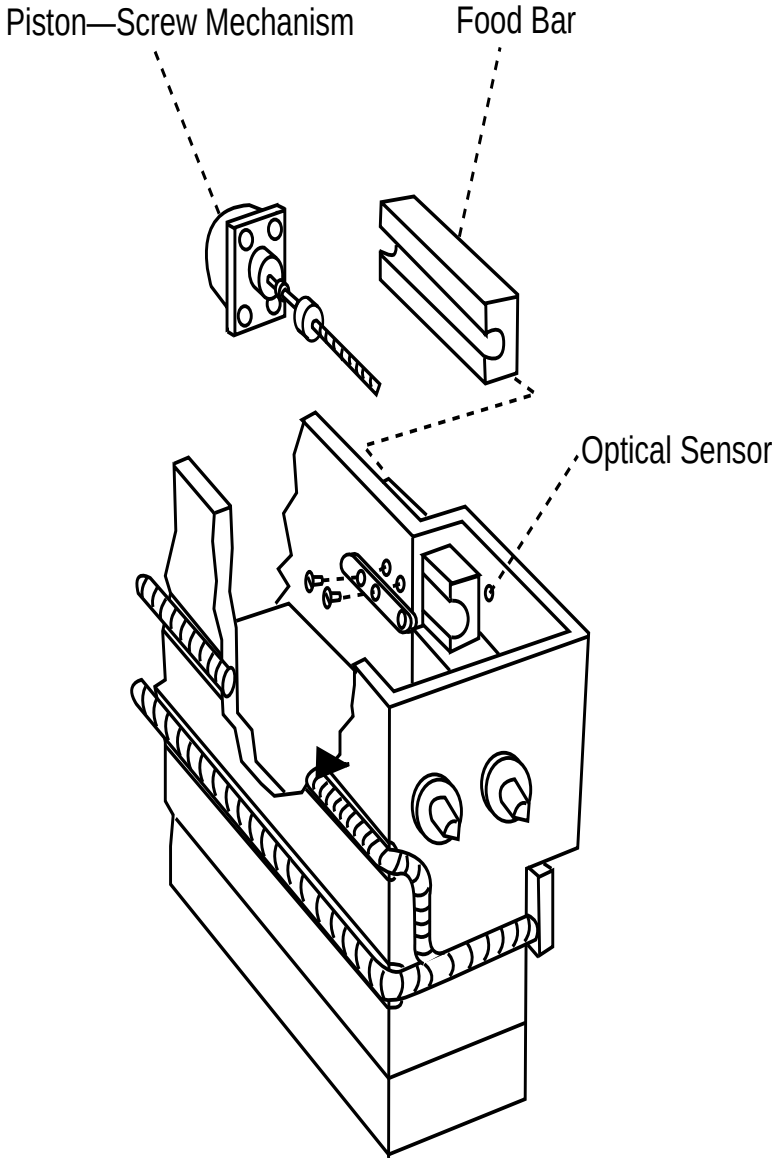
None

Publications

- Callahan, P.X., et al: Ames Research Center Life Sciences Payload Project for Spacelab Mission 3. *SAE Technical Paper Series 831094,* July 1983.
- Hogan, R.P. and B.P. Dalton: Performance of the Research Animal Holding Facility (RAHF) and General Purpose Work Station (GPWS) and other Hardware in the Microgravity Environment. *SAE Technical Paper Series 911567,* July 1991.
- *Ames Research Center, Life Sciences Payload, Spacelab-3, 60 Day Report*. P.X. Callahan, ed., NASA Ames Research Center, Space Life Sciences Payload Office, April 1985.



Watering System with Rodent Cage Configuration



Rodent Feeder for Spacelab-3

Missions Flown Through 1990:STS-51B/SL-3 (p. 92)

Research Animal Holding Facility (RAHF): Primate Cage Modules

Hardware Description

A cage module system supports the animal cages and air ducts through them, provides light and watering lixits within each cage, and electronically connects the cages to power and data systems. Modules also contain temperature and humidity sensors. The modules are designed to support cages specific to an animal species, and are interchangeable in that they require the same rack space and interface in the same manner with all RAHF subsystems. Any cage insert can be removed without disturbing the remaining specimens. Each cage is large enough to allow specimens unrestricted movement and is designed to ensure the specimen's physical safety.

Primate Cage Modules: The primate cage contains two windows, one behind the other, a solid window and a perforated window. A polycarbonate window on the front of the primate cage allows crew members to view the animals. A perforated polycarbonate window allows limited access to the primate after removal of the solid viewing window. A temporary restraint system (squeeze mechanism) allows the primate to be restrained inflight in an emergency situation. The squeeze wall can also be used to move the primate to the front of the cage for viewing. A lixit, which the primate must activate to obtain water, protrudes through the rear cage wall, and a pellet feeder occupies the upper left side wall. Animal movement is monitored by two infrared light sources and sensors on opposite sides of the cage watering and feeding locations.

Primate Feeder: The primate feeder consists of a cylindrical metal tube, with twelve individual tubes inside running from one end of the cylinder to the other, a rotating "gum-ball" receptacle. Each of the twelve tubes are connected at one end to the "gum-ball" receptacle, which receives a pellet from each of the tubes (tubes are spring-loaded at the other end). The receptacle rotates perpendicular to the long axis of the feeder, one space (tube) at a time when driven by a stepper motor. The motor is activated by the monkey pressing a switch inside the cage. The pellet is then ejected into a small cup which had a rubber cover through which the monkey can reach. The number of taps required and the time interval between pellets can be programmed by selector switches on the motor controller in the front section of the cage, normally set to the monkey's trained program. Each tube is filled and spring-loaded preflight with the primate food pellets. Conventional monkey chow pellets were not hard enough to tolerate the required spring load, so harder, high-sucrose pellets are used. For SL-3, primates were fed a commercial diet of small, white pellets, 300 mg each, provided by Bioserve, Inc. The feeder can be reloaded without removing the cage or animal.

Waste Management System: The waste management system attaches to the lower part of each drawer through a slide arrangement beneath the floor of the cages. Access through a door on the drawer front face permits changing of the waste tray for missions of more than ten-day duration. Aerodynamic drag on the waste products transports the liquid and solid matter to the collection system. Because the Spacelab long-axis is vertical during launch, the RAHF is on its side (horizontal) during this time. The RAHF is installed only on the port side of the Spacelab to orient the cage waste trays properly. In this position, animal cages are designed with the waste tray down in the 1 g direction to capture animal wastes during prelaunch and launch. During orbit, the normal airflow through the cage moves wastes into the waste trays. On landing, cages are oriented 90° from launch so that the 1 g vector is through the cage wall for a short period of time, prior to cage removal.

Specifications

Dimensions:	21.69 x 36.91 x 53.34 cm (cage size)
Weight:	18.3 kg (40.26 lb), empty
Power:	28 VDC, module; 110 VAC, cage
Capacity:	Primates weighing up to 1,200 g
Waste Control:	Waste trays with charcoal (0.25 in) and absorbent wick (0.5 in) filters
Internal Activity Monitor:	Reflection of 920 nm light beam

Data Acquisition

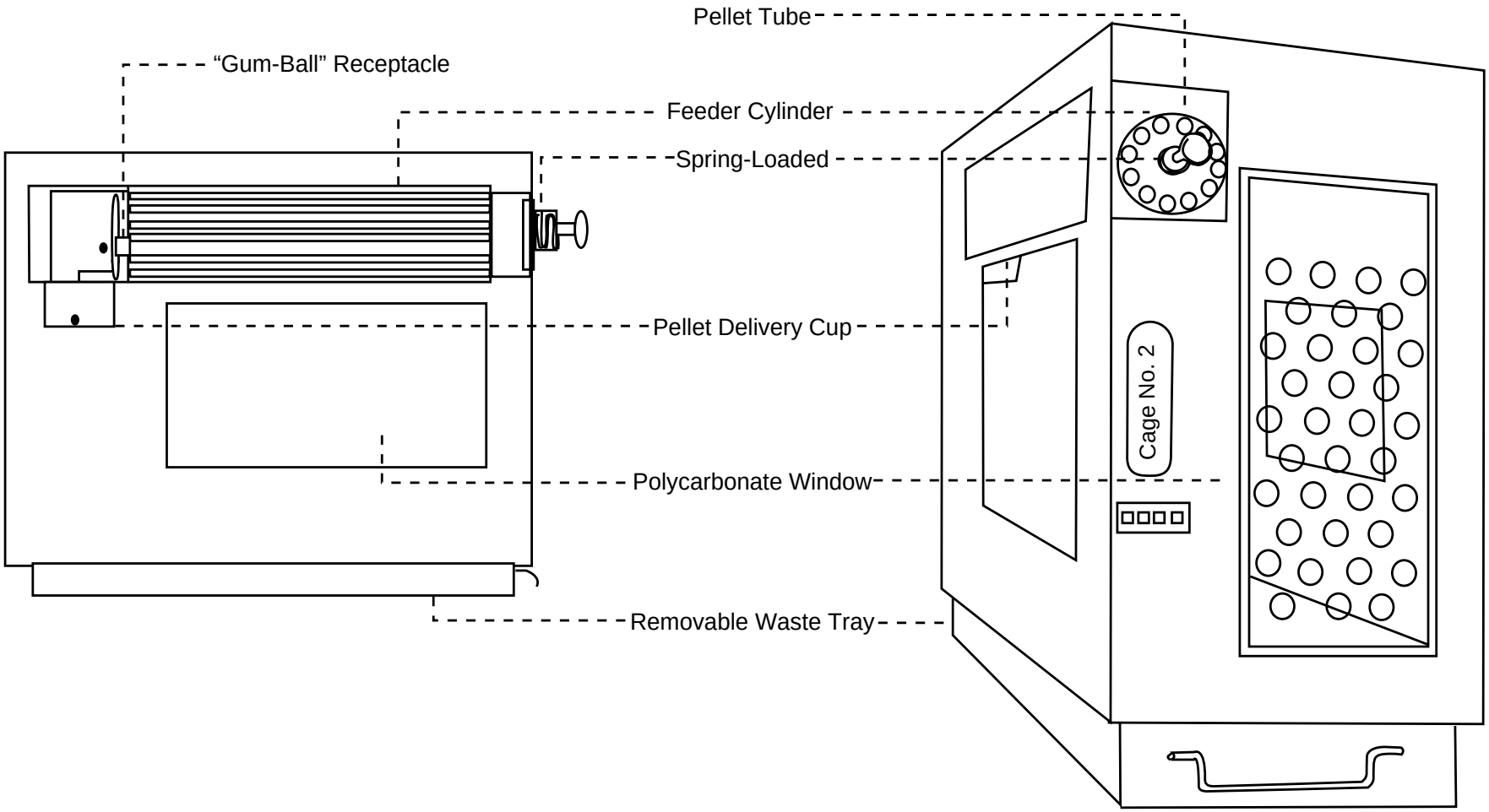
Food, water and activity counts

Related Ground-Based Hardware

None

Publications

- Callahan, P.X., et al: Ames Research Center Life Sciences Payload Project for Spacelab Mission 3. *SAE Technical Paper Series 831094,* July 1983.
- *Ames Research Center, Life Sciences Payload, Spacelab-3, 60 Day Report*. P.X. Callahan, ed., NASA Ames Research Center, Space Life Sciences Payload Office, April 1985.



Side View

Front View

Missions Flown Through 1990:STS-51B/SL-3 (p. 92)

Research Animal Holding Facility (RAHF): Rodent Cage Modules

Hardware Description

A cage module system supports the animal cages, air ducts through them, provides light and watering lixits within each cage and electronically connects the cages to power and data systems. Modules also contain temperature and humidity sensors. The modules are designed to support cages specific to an animal species, and are interchangeable in that they require the same rack space and interface in the same manner with all RAHF subsystems. Any cage insert can be removed without disturbing the remaining specimens. Each cage is large enough to allow specimens unrestricted movement and is designed to ensure the specimen's physical safety.

Rodent Cage Modules: Rodent cages are designed with a polycarbonate window in the partition between the two compartments so the crew can view both front and back rats by opening the cage drawer. Cage tops are hinged to access the animals sequentially and both had a hole large enough for the animal to reach the lixit valve installed in the air plenum above the cage to avoid disconnecting the plumbing on cage removal.

Rodent Feeder: Rodent food is supplied *ad libitum* in the form of a compressed diet bar. Rodent food is molded in rectangular bars which mount in a spring-loaded, side-mounted bar feeder. The bars are driven against a stop in such a way that the food bar is advanced as the rat con- sumes food, triggering a microswitch and a counter that records the number of clicks and, there- fore, the amount of food bar remaining. Food bars can be changed by crewmembers through the feeder cassette without removing animals from the cage.

Waste Management System: The waste management system attaches to the lower part of each drawer through a slide arrangement beneath the floor of the cages. Access through a door on the drawer front face permits changing of the waste tray for missions of more than ten days duration. In microgravity, air at a velocity of 9.2 m/min flows from the top of the cage to the bottom and through the waste collection system. Aerodynamic drag on the waste products transports the liquid and solid matter to the collection system. A heat-felted fiberglass pad, 0.5 inch thick, is impregnated with phosphoric acid for absorption of urine and bacterial growth control. Odor control is accomplished by means of a phosphoric acid-treated activated charcoal bed, 0.25 inches thick. Because the Spacelab long-axis is vertical during launch, the RAHF is on its side (horizontal) during this time. The RAHF is installed only on the port side of the Spacelab to orient the cage waste trays properly. In this position, animal cages are designed with the waste tray down in the 1 g direction to capture animal wastes during prelaunch and launch. During orbit, the normal airflow through the cage moves wastes into the waste trays. On landing, cages are oriented 90° from launch so that the 1 g vector is through the cage wall for a short period of time, prior to cage removal.

Specifications

Dimensions:	10.5 x 11.5 x 28 cm (compartment)
Weight:	Unknown
Power:	Unknown
Capacity:	One 400 g rodent/compartment
Waste Control:	Removable waste trays with charcoal (0.25 in) and absorbent wick (0.5 in) filters
Internal Activity Monitor:	Reflection of 920 nm light beam

Data Acquisition

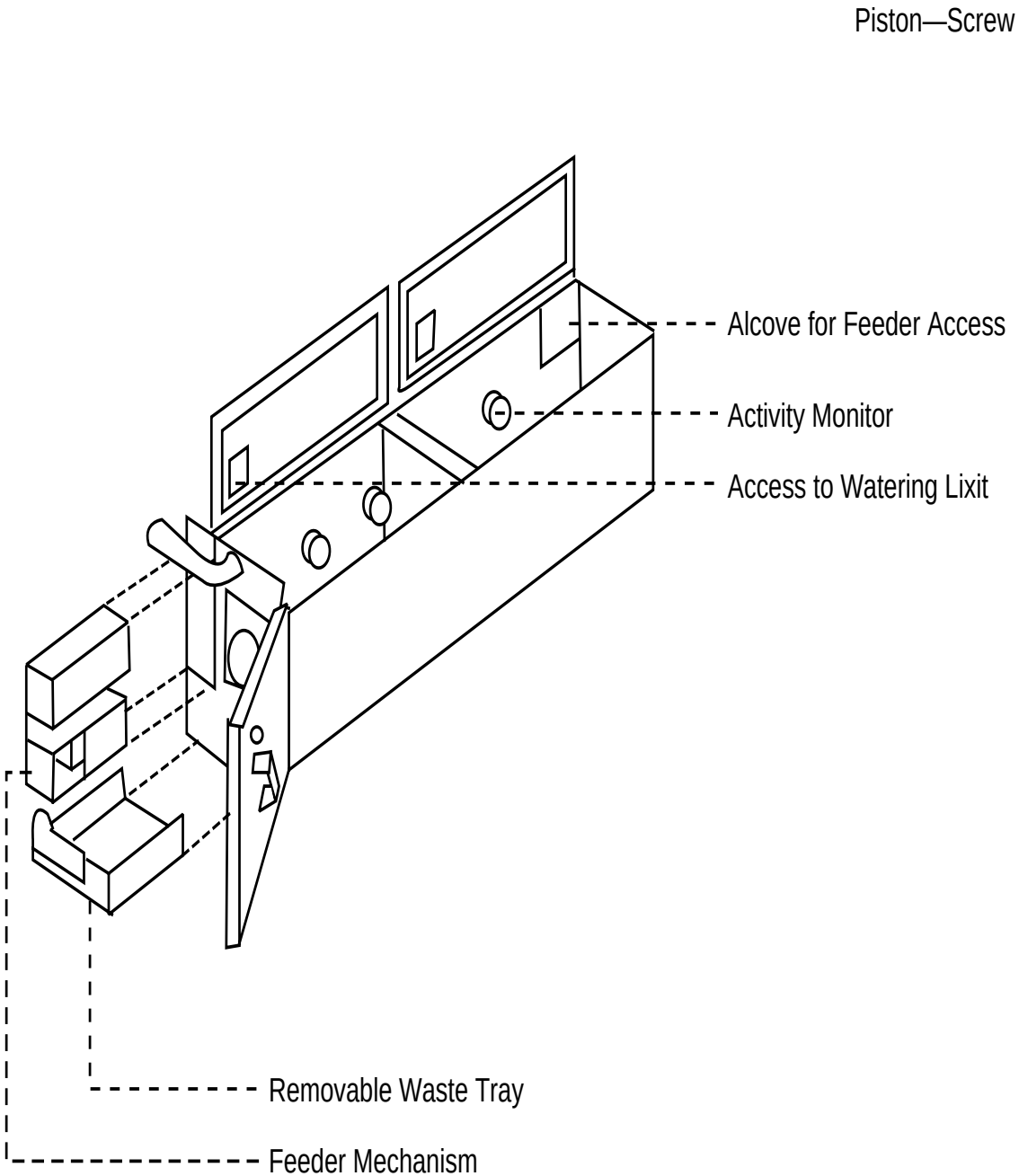
Food, water and activity counts

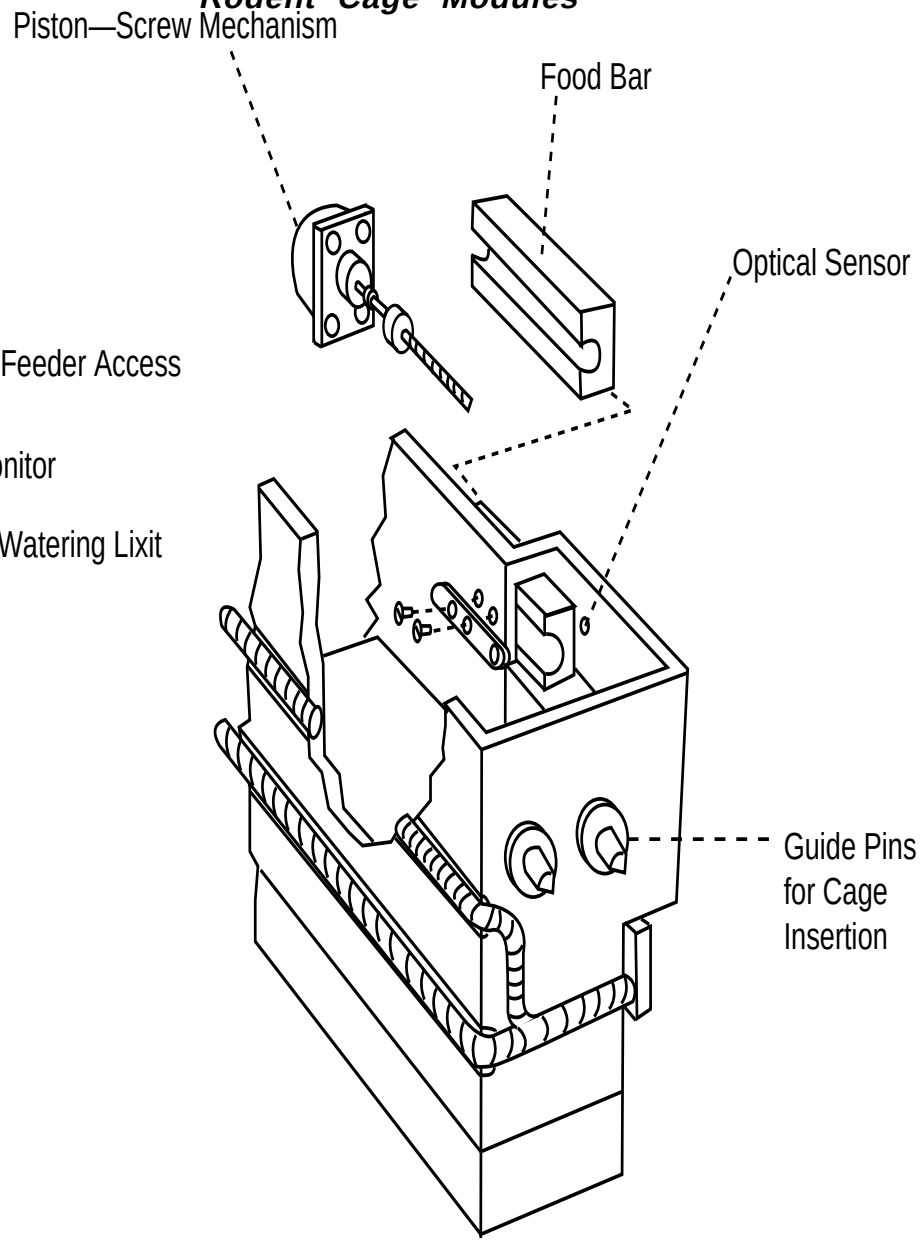
Related Ground-Based Hardware

None

Publications

- Callahan, P.X., et al: Ames Research Center Life Sciences Payload Project for Spacelab Mission 3. *SAE Technical Paper Series 831094,* July 1983.
- Hogan, R.P. and B.P. Dalton: Performance of the Research Animal Holding Facility (RAHF) and General Purpose Work Station (GPWS) and other Hardware in the Microgravity Environment. *SAE Technical Paper Series 911567,* July 1991.
- *Ames Research Center, Life Sciences Payload, Spacelab-3, 60 Day Report*. P.X. Callahan, ed., NASA Ames Research Center, Space Life Sciences Payload Office, April 1985.





Missions Flown Through 1990:STS-51B/SL-3 (p. 92)

Rodent Feeder for Spacelab-3 (rear feeder)

Sea Urchin Egg Package

Hardware Description

The Sea Urchin Egg Package was developed to enable the inflight fertilization and fixation of eggs of the sea urchin *Arbacia punctulata*, to allow for the determination of the effect of microgravity on the fertilization and development of echinoderm eggs. The experiment package containing sea urchin (echinoderm) eggs, sperm, and fixative is used to house and protect the experiment organisms during flight. By programming the mixing of eggs, sperm and fixative in each chamber, the rate of cell division, cell differentiation, and morphogenesis can be studied.

The experimental apparatus is a cylinder 8.2 cm in diameter and 17.1 cm long, consisting of eight specimen chambers. Each chamber is divided into three compartments so that sea urchin sperm and ova, and the fixative solution could be separated. Rotation of a handle actuates the piston in each chamber to provide fertilizing and fixing at discrete time intervals. The handle is rotated at 12° to the right and released, after which it returns to the start position. The chambers are made of acrylic plastic, and silicone rubber O-rings are used for dynamic seals on the sliding pistons. Each chamber will contain 4.2 ml of eggs and 0.45 ml of sperm in a sea-water solution, and 5 ml of fixative.

The original flight hardware was flown on Gemini-3, but the experiment was unsuccessful due to a failure of the handle operating mechanism and a fixative leakage (silicone rings were slightly permeable by several parts per million). A modification of the hardware was developed for flight on Biosatellite I/II, utilizing sixteen egg chambers and a motor-driven cam to actuate the piston in each chamber. Other intended modifications included a less-permeable O-ring and use of a hardware material that would not prove toxic to the experimental specimens. The experiment was canceled, though, because no treatment could be discovered which would detoxify the plastic hardware enough to successfully maintain the sea urchin sperm and unfertilized eggs.

Specifications

Dimensions: 8.5 cm (diameter) x 17.1 cm
Weight: 721 grams
Power: None

Data Acquisition

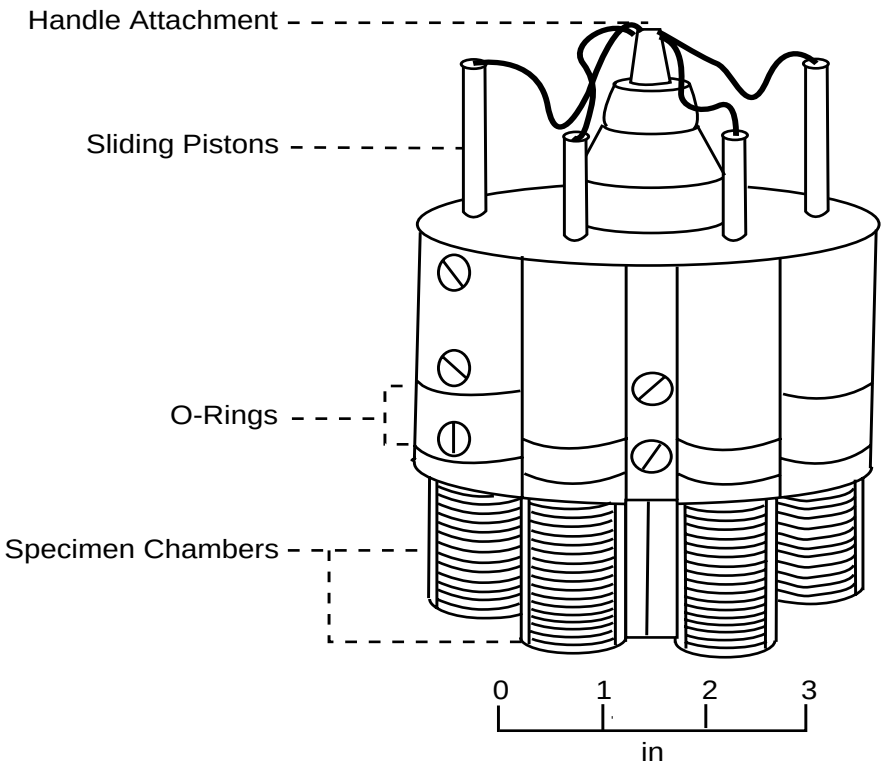
Inflight fixation

Related Ground-Based Hardware

None

Publications

- Young, R.S.: Sea Urchin Egg Fertilization and Development. *The Gemini Program Biomedical Sciences Experiments Summary.* E.O. Zeitler and T.G. Rogers, eds., NASA TM-X-58074, September 1971, pp. 245–247.
- Hacker, B.C.: *On the Shoulders of Titans: A History of Project Gemini.* NASA SP-4203, 1977, p. 537.
- Willoughby, R.: *Toxicity Problems in Plastic Hardware Designed for Biological Spaceflight Experiments.* NASA TM-X-1818, 1969.



Missions Flown Through 1990:Gemini III (p. 36)

Temperature Recording System

Hardware Description

The complete temperature recording system developed for Cosmos 1129 consists of a flight recorder, a ground readout unit, and any suitable analog or digital recorder. The flight recorder is completely self-contained and includes a temperature sensor, all necessary electronics for signal conditioning, processing, storing, control and timing, and a battery power supply. It is small, light, and sturdy with no moving parts. It is constructed of materials which are compatible with exposure to biological fluids (not immersion). It is capable of storing 2,048 8-bit temperature measurements taken at intervals selectable by factors of two from 1.875 up to 240 minutes, and data can be retained in memory for at least four months. The basic recorder can be modified to accommodate a variety of applications by adding memory to allow more data to be recorded, by changing the front end to permit measurements other than temperature to be made, and by using different batteries to realize various operating periods. Essential elements of the system include: a crystal-controlled oscillator with divide-down counters used to provide the basic system timing cycles and memory addressing; a temperature transducer and signal conditioner with gain and offset control; an analog-to-digital converter; a 2,048-byte memory array in which the temperature data are stored; control logic; sockets to allow calibration and start-up of the system, and to allow for data transfer to the ground readout unit; and a battery power supply with regulators.

In operation, the flight unit is activated by means of a special plug and then placed in a location where temperature is to be recorded. The recorder will then store readings taken at precise, regular, predetermined intervals, after which it automatically switches to an ultra-low power data-retention mode. After termination of the mission and recovery, the flight recorder is connected to the ground unit for data readout.

Specifications

Dimensions:	2.5 x 5.1 x 10.2 cm
Weight:	201 g
Power:	Self-Contained Lithium Battery
Range:	–15 to +45 °C
Accuracy:	± 0.5 °C
Sampling Rate:	1.875 minutes to 15 minutes
Data Capacity:	2,048 data points
Data-Acquisition Period:	21.33 days (max) at 15 minute sampling rate

Data Acquisition

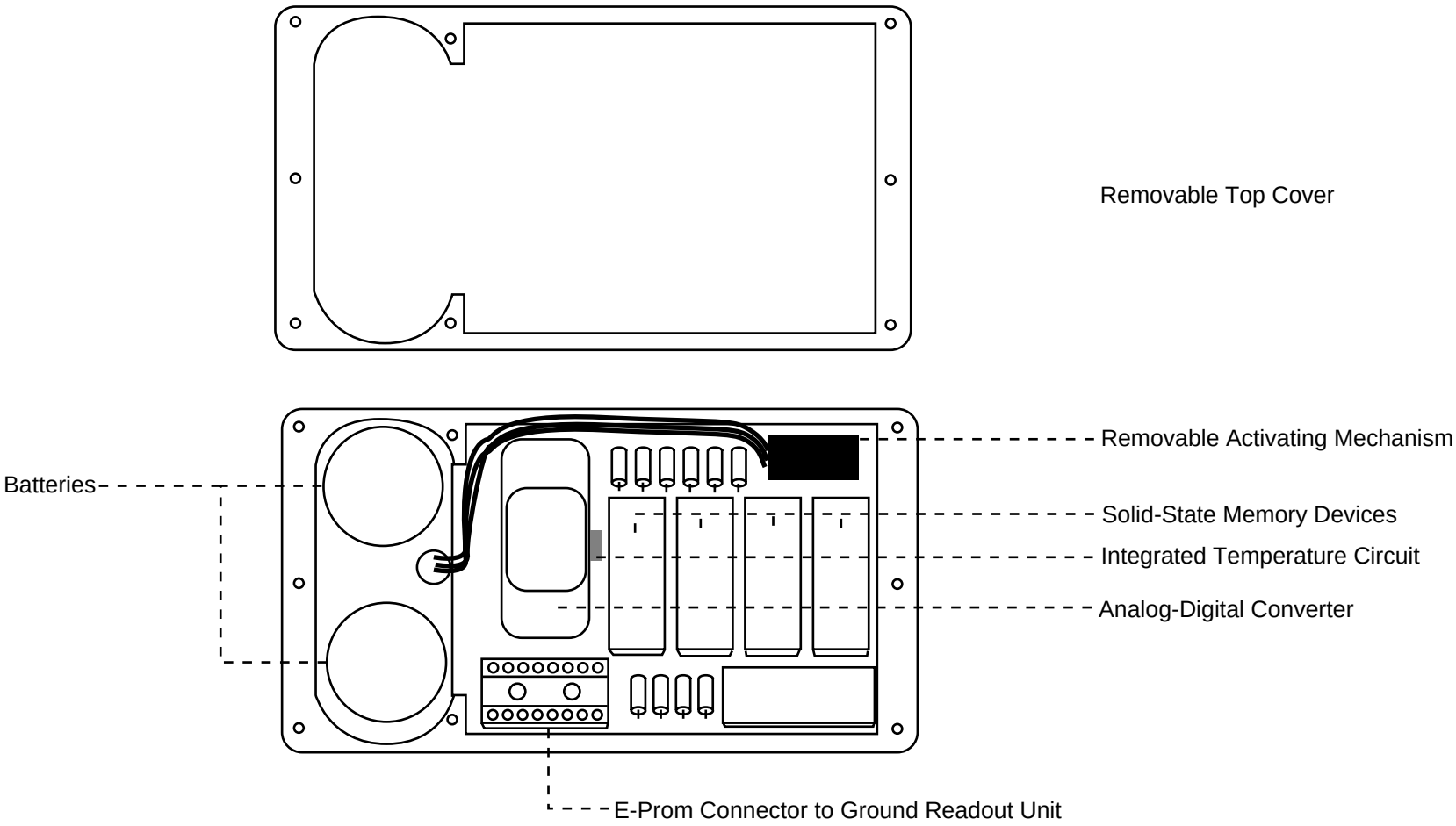
Ambient temperature data

Related Ground-Based Hardware

Ground Readout Unit: Stored flight data are read out from the recorder by means of a ground readout unit. Data are transferred from the flight unit to semipermanent, ultra- violet erasable, read-only memories in the ground unit via a cable. The ground unit contains numerous convenience features and safeguards to prevent accidental loss of data, and has analog, digital and visual LED outputs.

Publications

- Rasmussen, D.N. and R.C. Mains: U.S. Bioinstrumentation on Cosmos 1514. *Final Reports of U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514.* NASA TM-88223, 1986, pp. 37–70.
- Deboo, G.J., et al: *A Solid-State Digital Temperature Recorder for Space Use.* NASA TM-81267, 1981.



Missions Flown Through 1990:Cosmos 1129 (p. 139)

Temperature Recording System: Modification 1 4-Channel Ambient Temperature Recorder

Hardware Description

The 4-Channel Ambient Temperature Recorder (ATR-4) used on Cosmos 2044 is a forerunner to the Shuttle-qualified ATR-4, which is used to support current experiments aboard the Space Shuttle. It is a self-contained, battery-powered device that can be placed in almost any environment to provide recording from one to four temperature sensors. Channel 1 can be set to measure the container's ambient temperature or external temperature from a probe attached to Channel 1's connector. Remote temperatures can be measured using temperature probes connected to Channels 2-4.

The recorder periodically senses and stores (in its solid state memory) up to four channels of temperature data. These stored values can be read out postflight using a serial interface unit and an IBM-compatible computer. The sample rate and number of channels used are selectable, but the total number of samples is limited by the size of the internal memory (32,768 samples). The recorder stops recording when the memory capacity is reached. The internal power supply consists of two lithium batteries. The case is made of aluminum and is approximately the size of a package of cigarettes. The unit has an O-ring seal to protect its interior from fluids.

For Cosmos 2044, the unit was mounted to the outside of the biosatellite, in conjunction with radiation dosimetry studies. Temperature probes were distributed over the plates inside the "clamshell" containers which housed the various radiation dosimeters and embedded to the side of the containers housing the Sealed Plastic Stacks (see *Cosmos 2044 Radiation Dosimeters* for more details on dosimeters). This recorder is accurate to ±1 °C over a temperature range from –50 to +50 °C.

The Shuttle-qualified ATR-4 temperature range is from –40 to +60°C. This unit was flown on recent shuttle flights STS-34 and STS-32, in support of the *Growth Hormone Concentration and Distribution (GHCD)* and *Characterization of Neurospora Circadian Rhythm (CNCR)* experiment payloads, respectively.

Specifications

Dimensions:	24 x 58 x 90 mm
Weight:	130 g
Power:	2 Self-Contained Lithium Batteries
Range:	–50 to +50 °C
Accuracy:	± 1 °C
Channels:	1 to 4, selectable
Sample Rates:	1.87, 3.75, 7.5, &15 min, selectable
Data Acquisition Period:	1 Channel: 42 Days (1.87 min) 341 Days (15 min) 4 Channel: 10 Days (1.87 min) 85 Days (15 min)

Data Acquisition

Temperature data

Related Ground-Based Hardware

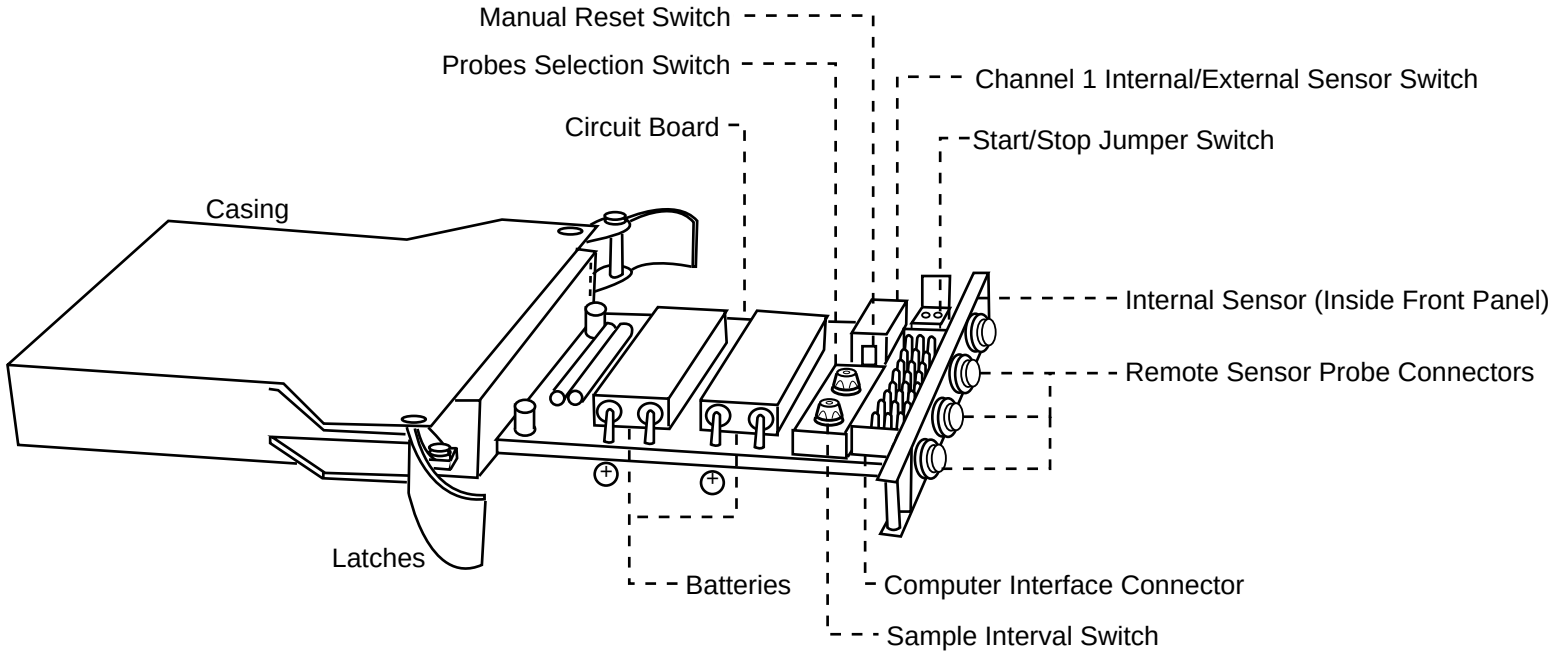
IBM-Compatible Computer and Interface Unit: For initialization of the ATR-4 and readout of ATR-4 data.

ATR-4 System Software: For readout and transfer of ATR-4 data to computer disk and paper copy.

Field Tester: For final checkout of ATR-4 operation.

Publications

- *Life Sciences Laboratory Equipment Catalog.* NASA Ames Research Center, Space Life Sciences Payloads Office, May 1989, p. 2.
- Skidmore, M.G. and J. Connolly: U.S. Flight and Ground Support Hardware. *Final Reports of the U.S. Experiments Flown on the Soviet Biosatellite Cosmos 2044, vol. 1.* J.P. Connolly, R.E. Grindeland and R.W. Ballard, eds., NASA TM-108802, September 1994, pp. 47–66.



Missions Flown Through 1990:Cosmos 2044 (p. 162), STS-34/GHCD (p. 104), STS-32/CNCR (p. 106)

Tradescantia (Flowering Plant) Experiment Package

Hardware Description

The Tradescantia (flowering plant) experiment packages are constructed of polypropylene plastic to minimize absorption and scattering of the gamma rays from the onboard radiation source. The packages are somewhat boomerang-shaped plastic housings 42 cm long, 4.7 cm wide, and 4.7 cm deep. Each package holds 32 plants with the roots sealed in a tube filled with Hoagland's nutrient solution. A comb-like retainer prevents the nutrient tubes from moving as a result of vibration, centrifugation, etc. Tubes are stacked four deep and four across, for a total of sixteen tubes in each end of the polypropylene package. When cuttings are placed in nutrient tubes, they form small, light, compact units suitable for use in the confines of a crowded Biosatellite. Plastic fibers are placed around loose buds or stems during the loading process as shock-absorbing packing. Small holes in the cover permit air exchange and some temperature control. A thermistor is installed through the housing wall to monitor the package temperature.

Radiation Dosimeters: Numerous passive dosimeters of LiF powder are placed in the root and bud zones. A dosimeter is placed into each of the nutrient tubes in the root zone. For the bud zones, dosimeters are attached along the inside wall and on the retainer pins of the housing.

Specifications

Dimensions: 42 x 4.7 x 4.7 cm
Weight: Unknown
Power: None

Data Acquisition

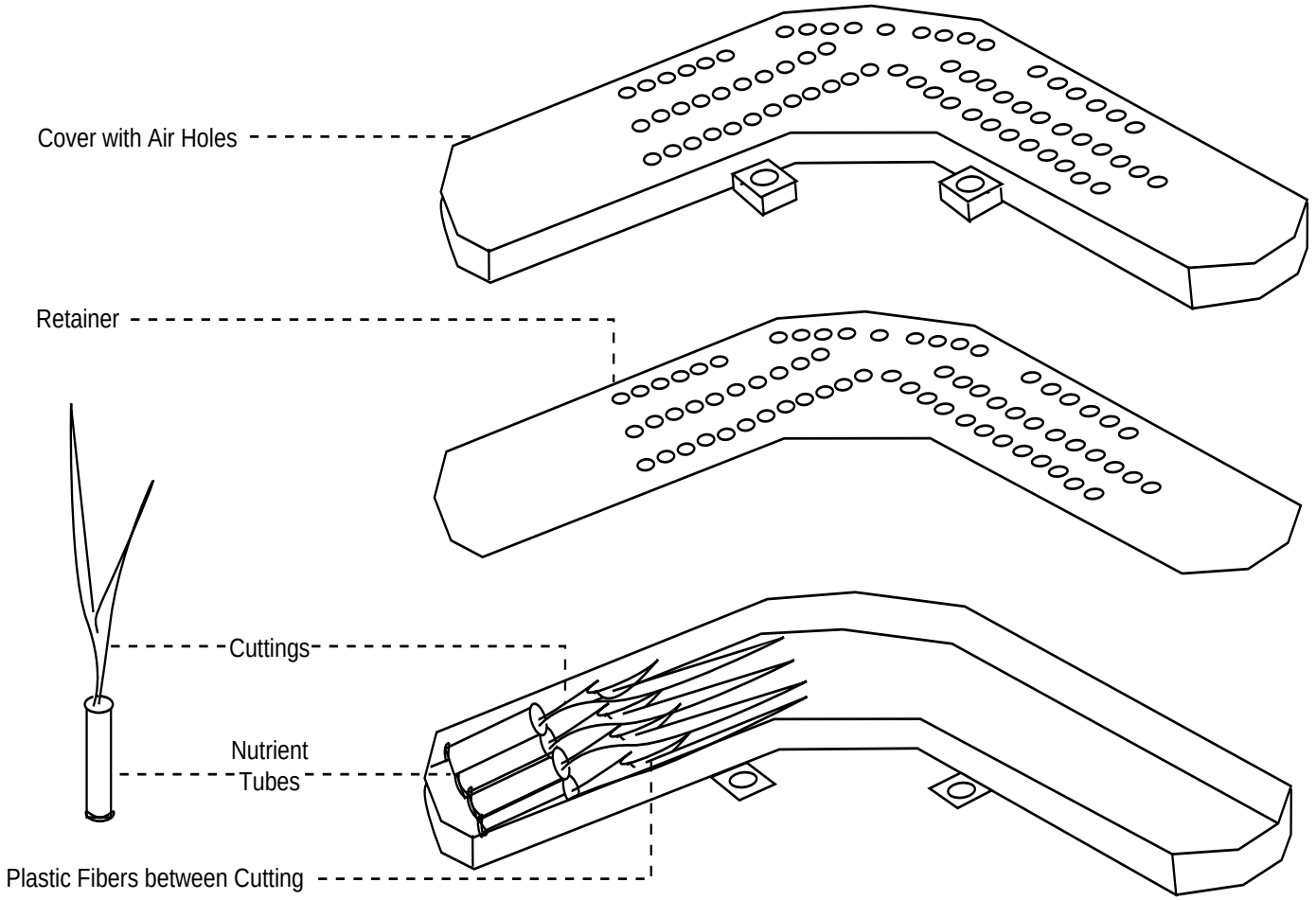
Radiation and temperature data

Related Ground-Based Hardware

None

Publications

- Sparrow, A.H., et al.: Genetic and Cytologic Studies of Tradescantia Irradiated During Orbital Flight. *Bioscience,* vol. 18, no. 6, June 1968, 582–590.
- *Biosatellite Project Historical Summary Report.* J.W. Dyer, ed., NASA TM-X-72394, December 1969.



Missions Flown Through 1990:Biosatellite I/II (p. 46)

Tribolium (Flour Beetle) Experiment Package

Hardware Description

The Tribolium (flour beetle) experiment package consists of a several plastic modules each with three compartments. Each compartment contains an aluminum insert holding two felt layers sandwiched between tissue papers. Holes are punched in each piece of felt, then one or two pupae are positioned in each hole in the felt inserts, cushioned between layers of tissue paper. The packages are constructed with integral heating strips and a preset thermostat; temperature control is automatic and required 28 V dc. There are two Tribolium packages, each of which contain 720 pupae.

Radiation Dosimeters: Four LiF disc dosimeters are inserted between two tissue papers with a pupae layer on either side then inserted into the plastic module.

Specifications

Dimensions: Unknown
Weight: Unknown
Power: None

Data Acquisition

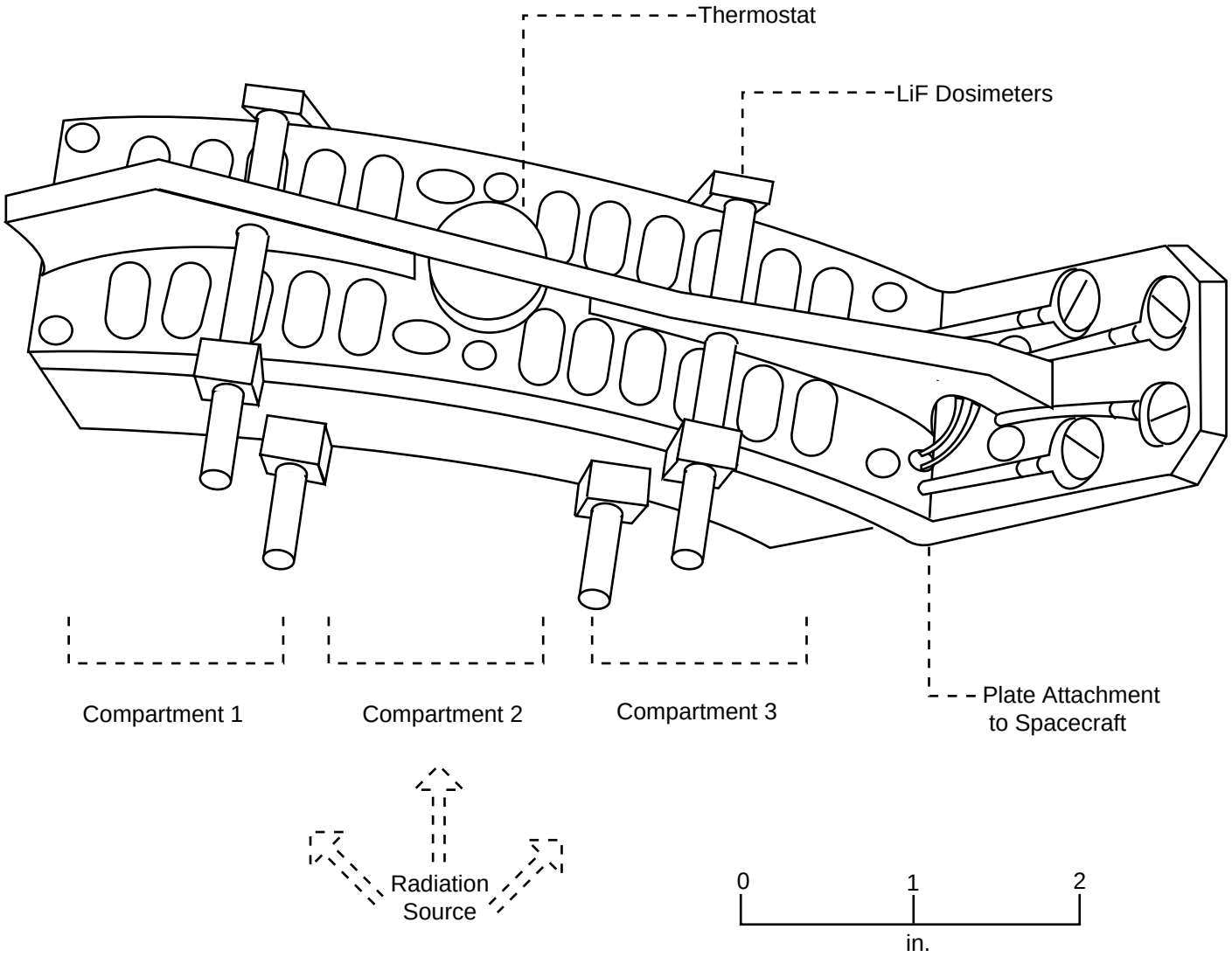
Radiation data

Related Ground-Based Hardware

None

Publications

- Slater, J.V., et al.: Effect on a Flour Beetle of Irradiation During Space Flight. *Bioscience,* vol. 18, no. 6, June 1968, pp. 595–597.
- *Biosatellite Project Historical Summary Report.* J.W. Dyer, ed., NASA TM-X-72394, December 1969.



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Hardware Description

The Triticum (wheat seedling) experiment package consists of three cylindrical, nontoxic plastic chambers about 3 inches in diameter and 6.5 inches in height. The chambers are fixed to a common base and are closed with individual lids with gaskets. Each chamber has an insulating blanket to eliminate light and minimize heat loss. Each chamber contains a seed-holding stalk placed in its long axis, and a fourth, larger chamber contains three similar seed-holding stalks. The polycarbonate plastic stalks are hollow with angled side arms spirally arranged at 120° intervals so that each seed, when fixed, has the maximum amount of space in which to grow without its roots touching another seedling or the chamber wall. The arms are set at 45° with one end of the central reservoir, a slurry of finely ground vermiculite and water in the interior of the hollow stalk. Each chamber contains a thermistor for recording temperature.

Presoaked seeds are inserted into the rubber diaphragms of the stalks thoroughly wetted with ground vermiculite. Each seed is inserted brush end first halfway through the hole burned in each cap, and then water is injected into the air spaces of the arm core. Water loss is prevented by application of lanolin and beeswax (4:1 by weight) at the point of contact between the rubber diaphragm and the seed, after the seed is planted.

The large chamber contains three polycarbonate stalks of twelve seeds each. Of the three small chambers, two are equipped to spray-fix the fifteen seedlings during orbit. Two spray-fix assemblies, each with a capacity of 25 ml, are arranged to discharge their contents through nozzles into the chamber to which they are attached, so that a fine spray of fixative bathes the seedlings. The firing of a squib activates a plunger which discharges the fixative at high pressure through the nozzles.

Specifications

Dimensions: 3 in diam. x 6.5 in ht. (chambers)
Weight: Unknown
Power: Unknown

Data Acquisition

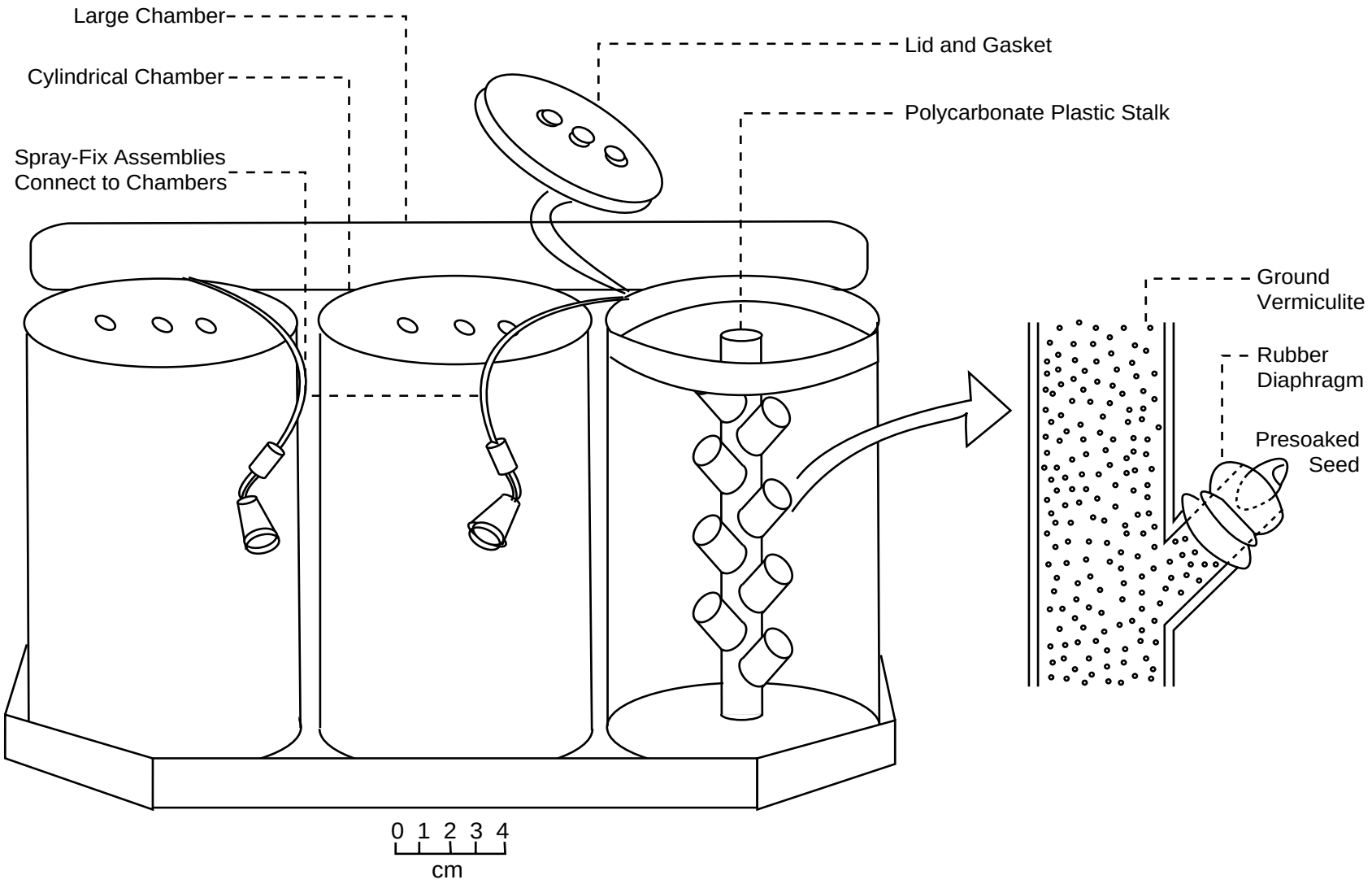
None

Related Ground-Based Hardware

None

Publications

- Lyon, C.J., et al.: Wheat Seedling Experiments. *Bioscience*, vol. 18, no. 6, June 1968, pp. 632–633.
- *Biosatellite Project Historical Summary Report.* J.W. Dyer, ed., NASA TM-X-72394, December 1969.



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