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## BIOSPEX: Biological Space Experiments

A Compendium of Life Sciences

Experiments Carried on U.S. Spacecraft

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## INTRODUCTION

The United States space effort has had a long, though not always well known, history of Life Science experimentation. Long before the birth of the National Aeronautic and Space Administration biological payloads were being launched. The first documented flight carrying a living payload was a V-2 rocket in 1948. The captured rocket carried a primate, Albert, in a specially designed nosecone. The Navy was responsible for this flight, and as time progressed, the Army became involved.

The Army used a ballistic rocket as the means of carrying the experiments. After several unsuccessful and semi-successful flights, the historic Abel and Baker flight was accomplished. The two primates carried on the flight were returned alive and well. From this point on, more and more Life Science experiments were returned alive.

With the beginning of NASA, the military surrendered sole rights to flight studies. The agency started its Life Sciences program with chimpanzee flights in preparation for Project Mercury. From the space experience with Ham and Enos, the chimps, it was deemed that the space environment was safe for man, and Alan Shepard and John Glenn were launched into the relative unknown.

The early Mercury flights marked the beginning of inflight biomedical experimentation on humans. During all of the manned spaceflight programs, a large number of experiments have been conducted on the flight crews. There have been numerous biological studies in the space environment ranging from high energy particle effects on cellular organisms to fully instrumenting and flying a monkey. Satellites have been solely devoted to biological investigations, such as the Biosatellite series and the joint U.S. - U.S.S.R. KOSMOS 782 mission.

The following document is a compendium of Life Science investigations that have taken place on U.S. spacecraft. Previously, there had been no complete compilation of the experiments, making it difficult to determine what has been attempted and accomplished in space Life Sciences. It is divided

into chapters for human, animal, plant and microorganism specimen types. Each chapter is in order alphabetically by Principal Investigator.

Subsequent to its initial publication, BIOSPEX was distributed to Principal Investigators of each experiment and other Life Scientists for review and comment. An evaluation form was included requesting suggestions for changes they would like to see in the revised edition. In response to these helpful and much appreciated suggestions, more concise descriptions of the experiments were made. A separate bibliography, an index, and an investigator address list have also been added to this version. It is anticipated that this document will be updated and reissued as new information is obtained during the upcoming Shuttle era.

#### ACKNOWLEDGEMENTS

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MISSIONS CARRYING BIOLOGICAL OR MEDICAL PAYLOADS

<u>Mission</u>	<u>Date</u>	<u>Duration</u>	<u>Comments</u>
Blossom 3	6/18/48	NA	Carried a Rhesus monkey ("Albert") as first biological rocket payload; monkey not recovered.
Blossom 4	10/48	NA	Carried a Rhesus monkey; parachute failure and monkey not recovered.
Blossom 5	5/49	NA	Carried a Cynomolgus monkey; parachute failure and monkey not recovered.
Blossom 6	5/49	NA	Carried a Cynomolgus monkey; parachute failure and monkey not recovered.
Blossom 7	7/50	NA	Last V-2 flight; carried a mouse; parachute failure and mouse not recovered.
Aerobee 1	4/18/51	NA	Carried a Capuchin monkey into sub-orbital flight; not recovered.
Aerobee 2	9/20/51	NA	Carried a Rhesus monkey and 11 mice; animals landed alive, but monkey died at recovery site due to heat.
Aerobee 3	5/21/52	NA	Two Capuchin monkeys ("Mike" and "Patricia") and 2 mice flown; all recovered alive, showed no ill effects from flight.
Mouse-In-Able 1	4/23/58	20m	Carried mouse ("Wickie") into sub-orbital flight in a Thor-Able nosecone; neither mouse nor nosecone were recovered.
Mouse-In-Able 2	7/9/58	20m	Carried mouse ("Laska") into sub-orbital flight, monitoring heart rate; mouse not recovered.

<u>Mission</u>	<u>Date</u>	<u>Duration</u>	<u>Comments</u>
Mouse-In-Able 3	7/23/58	20m	Carried mouse ("Benji") into sub-orbital flight, monitoring heart rate; mouse not recovered.
AM #13 (Army Medical sounding rocket)	12/58	NA	Carried Squirrel monkey ("Old Reliable") and <u>Neurospora</u> spores; <u>Neurospora</u> not recovered.
AM #16	5/59	NA	Carried Rhesus and Squirrel monkeys ("Able" and "Baker") and biological specimens; partially successful.
AM #23	9/59	NA	Carried various biological specimens including sea urchin eggs; not recovered.
Little Joe 3 (Mercury)	12/4/59	11h,6m	Carried Rhesus monkey ("Sam"). High altitude abort test.
Little Joe 4	1/21/60	8h,35m	Carried Rhesus monkey ("Miss Sam"). Evaluated launch and abort systems.
Discoverer XVII	1960	3d	Investigated the space environment using a number of cell types.
Discoverer XVIII	1960	3d	Investigated the space environment using a number of cell types.
Discoverer XXXII	1960	3d	Investigated HZE particles using corn seeds.
NERV 1	1961	26m	Carried <u>Neurospora crassa</u> .
Mercury 2 (MR-2)	1/31/61	16h,39m	Carried chimpanzee ("Ham"); booster oversped.
Mercury 3 (MR-3) (Alan B. Shepard, Jr.)	5/5/61	15m	First American in space.
Mercury 4 (MR-4) (Virgil I. Grissom)	7/21/61	16m	Suborbital.
Mercury 5 (MA-5)	11/29/61	3h,20m (3 rev)	Carried chimpanzee ("Enos")

<u>Mission</u>	<u>Date</u>	<u>Duration</u>	<u>Comments</u>
Mercury 6 (MA-6) (John Glenn)	2/20/62	4h,55m (3 rev)	First manned orbital flight.
Mercury 7 (MA-7) (Scott Carpenter)	5/24/62	4h,56m (3 rev)	Yaw error caused landing 250 mi. downrange - recovery in 3 hrs.
Mercury 8 (MA-8) (Walter M. Shirra Jr.)	10/3/62	9h,13m (6 rev)	
Mercury 9 (MA-9) (L. Gordon Cooper)	5/15/63	34h,20m (22 rev)	
Gemini III (Virgil I. Grissom, John W. Young)	3/23/65	4h,53m (3 rev)	First 2-man space flight; sea urchin experiment failed.
Gemini IV (James A. McDivitt, Edward H. White)	6/3-7/65	97h,40m (62 rev)	First Extra-Vehicular Activity (EVA) 22 min.
Gemini V (L. Gordon Cooper, Charles Conrad, Jr.)	8/21-29/ 65	190h,56m (120 rev)	Demonstrated physiological feasi- bility of lunar mission.
Gemini VII (Frank Borman, James A. Lovell, Jr.)	12/4-18/ 65	330h,35m (206 rev)	Extension of physiological test- ing. Evaluated light-weight pressure suit.
Gemini VI-A (Walter M. Shirra, Jr., Thomas P. Stafford)	12/15-16/ 65	25h,51m (15 rev)	Conducted rendezvous with Gemini VII.
Gemini VIII (Neil A. Armstrong, David R. Scott)	3/16-17/ 66	10h,42m (7 rev)	Rendezvous and dock with Agena target vehicle.
OV1-4 (U.S. Air Force)	3/30/66	720h	Non-recoverable satellite containing <u>Spirodella</u> & <u>Chlorella</u> ; <u>Chlorella</u> experiment failed inflight.
Gemini IX	5/17/66		Not launched.

<u>Mission</u>	<u>Date</u>	<u>Duration</u>	<u>Comments</u>
Gemini IX-A (Thomas P. Stafford, Eugene A. Cernan)	6/3-6/66	72h,21m (44 rev)	EVA of 2h, 2m; carried microorganisms
Gemini X (John W. Young, Michael Collins)	7/18-21/ 66	70h,47m (43 rev)	EVA of 45m (terminated due to fumes); umbilical EVA of 27 min.
Gemini XI (Charles Conrad, Richard F. Gordon, Jr.)	9/12-15/ 66	71h,17m (44 rev)	EVA of 2h, 55m; umbilical EVA of 44m. Reached record altitude of about 1400 km (870 mi); carried <u>Neurospora crassa</u> .
Gemini XII (James A. Lovell, Jr., Edwin E. Aldrin, Jr.)	11/11-15/ 66	94h,34m (59 rev)	EVA of 5h, 37m; last Gemini mission; carried frog eggs and microorganisms.
Biosatellite I	12/14/66		Spacecraft did not reenter on command and burned on subsequent reentry after 60 days in orbit.
Biosatellite II	9/7-9/67	2d	Returned 1 day earlier than scheduled; carried 13 biological experiments.
Aerobee 150A	12/5/67	460s	Investigated gravity preference of a white rat.
Apollo I (AS204) (Virgil I. Grissom, Edward H. White, Roger B. Chaffee)	1/27/67		Flight test; flash fire in space- craft killed 3 astronauts; in- flight medical experiments pro- gram was cancelled.
Apollo VII (Walter M. Shirra, Jr., Donn F. Eisele, Walter Cunningham)	10/11-22/ 68	260h,10m	Astronauts developed colds in orbit.
Apollo VIII (Frank Borman, James A. Lovell, Jr. William A. Anders)	12/21-27/ 68	147h,1m (10 lunar orbits)	First lunar orbital mission.
Apollo IX (James McDivitt, David Scott, Russell Schweickart)	3/3-13/ 69	241h, 1m	First flight manned lunar hard- ware in earth orbit; EVA of 37m.

<u>Mission</u>	<u>Date</u>	<u>Duration</u>	<u>Comments</u>
Apollo X (Eugene A Cernan, John W. Young, Thomas P. Stafford)	5/18-26/ 69	192h,3m	First lunar orbital mission with complete Apollo spacecraft.
Biosatellite III	6/29/69- 7/7/69	8 1/2d	Carried pig-tailed monkey; deteriorating physiological condition required early call-down.
Apollo XI (Neil A. Armstrong, Michael Collins Edwin E. Aldrin, Jr.)	7/16-24/ 69	195h,18m	First manned Lunar landing; time on the moon = 21h,20m.
Apollo XII (Charles Conrad, Jr., Richard F. Gordon, Jr., Alan L. Bean)	11/14-24/ 69	244h,36m 36m	Second lunar landing; EVA of 15h, 30m; time on the moon = 31h,31m.
Apollo XIII (James A. Lovell, Fred W. Haise, Jr., John L. Swigert, Jr.)	4/11-17/ 70	142h,54m	Third lunar landing mission aborted after 56h, GET due to loss of pressure in LOX in Service Module and failure of fuel cells 1 & 3; LM provided power and life support until transfer to CM for reentry.
Apollo XIV  (Alan B. Shepard Stuart A. Roosa Edgar D. Mitchell)	1/31/70-  2/9/71	216h,02m	Third lunar landing; time on the moon = 33h,30m.
Apollo XV (David R. Scott, Alfred M. Worden, James B. Irwin)	7/26/71- 8/7/71	295h,11m	EVA of 18h, 34m; fourth lunar landing; time on the moon = 66h,55m.
Apollo XVI (John W. Young, Thomas K. Mattingly, II, Charles M. Duke)	4/16-27/ 72	265h,51m	Fifth lunar landing; EVA of 20h, 14m; total lunar stay = 71h, 02m; lunar rover driven 26.7 km.
Apollo XVII (Eugene A. Cernan, Ronald E. Evans, Harrison H. Schmitt)	12/7-19/ 72	301h,51m	Sixth lunar landing; last Apollo mission; EVA of 22h, 5m; total lunar stay = 74h,59m; lunar rover driven 35 km.

<u>Mission</u>	<u>Date</u>	<u>Duration</u>	<u>Comments</u>
OFO-1(A)	11/9-15/ 70	144h	Studied vestibular nerve activity and adaptation of the otolith system in two bull frogs.
Skylab 2 (Charles Conrad, Jr., Joseph P. Kerwin, Paul J. Weitz)	5/25/73- 6/22/73	162h,49m (28+d)	Conducted medical experiments; repaired Skylab parasol.
Skylab 3 (Alan L. Bean, Owen K. Garriott, Jack R. Lousma)	7/28/73- 9/25/73	1427h,09m (59+d)	Total EVA of 27h, 26m; carried two spiders and killifish.
Skylab 4 (Gerald Carr, Edward Gibson, William Pogue)	11/16/73- 2/8/74	2017h,15m (84+d)	Obtained medical data on crew; total EVA of 44h, 40m; observed comet Kohoutek.
Apollo-Soyuz Test Project (Donald K. Slayton, Thomas P. Stafford, Vance D. Brand, Alexei A. Leonov, Valeri N. Kubasov)	7/15-24/ 75	217h,28m (9d)	First manned joint US-USSR Space effort; carried killifish.

PRINCIPAL INVESTIGATOR(S): W. Carter Alexander, Carolyn S. Leach, and Craig L. Fischer

EXPERIMENT TITLE/NUMBER: Clinical Biochemistry

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health, Hematology

OBJECTIVES: To provide routine clinical data for assessment of preflight crew physical status and for postflight comparisons; to detect clinical or pathological abnormalities which might have required remedial action preflight; to discover as early as possible any infectious disease process during the postflight quarantine periods following certain missions; and to obtain fundamental medical knowledge relative to man's adjustment to and return from the space flight environment.

PROTOCOL: Blood samples were obtained, frozen and transported for analysis. Critical analyses were done before freezing. There was withdrawal of 20 ml of venous blood 3 times before flight (F-30 days, F-15, and F-5), and blood taken at R+2hr, R+1 day, R+6 days, and R+13 days. Urine samples were taken at the same time as the blood. A general exposure history was taken, and ground controls were utilized.

EQUIPMENT: Blood and urine collection devices and assay equipment.

RESULTS: There were no values out of the normal range, but there were changes between pre- and postflight levels. In the blood serum as well as in the blood constituents, there was a decrease in potassium, magnesium, lactic dehydrogenase, creatine phosphokinase, albumin, uric acid, triglycerides, and cholesterol. There was an increase in creatine, total protein, BUN, and glucose. In the urine samples, there was an increase in electrolyte retention with a coincident decrease in the volume and hyperosmolality (reestablishing the fluid and electrolyte balance). A decrease in the excreted uric acid was also found.

CONCLUSIONS: The accumulated data suggest that the objectives were met by the program. All changes ascribed to the space flight environment were subtle, whereas clinically significant changes were consistent with infrequent illnesses unrelated to the space flight exposure.

PUBLICATIONS: 8

PRINCIPAL INVESTIGATOR(S): R. E. Allen, G. H. Barlow, Milan Bier, P. E. Bigazzi, R. J. Knox, F. J. Micale, G. V. F. Seaman, J. W. Vanderhoff, C. J. Van Oss, W. J. Patterson, F. E. Scott, P. H. Rhodes, B. H. Nerren, and R. J. Harwell

EXPERIMENT TITLE/NUMBER: Electrophoresis Technology, MA-011

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human, Animal

DISCIPLINE(S): Cell biology

OBJECTIVES: To conduct engineering and operational tests of a space-rated static electrophoresis separation apparatus and to further current research efforts through separation of similar cellular species.

PROTOCOL: An electrophoresis or isotachophoresis column was removed from its storage location and installed in the electrophoresis unit in space. Fluid couplings were secured to each electrode chamber of the electrophoresis columns only. The slide containing a specific frozen sample was removed from the cryogenic freezer and inserted into the column. A camera mounted on the electrophoresis unit cover photographed critical control positions and digital readouts during each column operation. Following each electrophoresis separation, the electrophoresis columns were frozen by the thermoelectric module and then removed from the cradle. The crewman removed each electrode chamber from the columns and placed the column in the cryogenic freezer for return to Earth. The isotachophoresis columns were neither frozen nor returned, but only photographed in orbit during their operation.

EQUIPMENT: An electrophoresis unit, a cryogenic freezer, eight experiment columns (six electrophoresis, two isotachophoresis), and eight sample insertion slides.

RESULTS: Separation of human, rabbit and horse erythrocytes was accomplished. Human kidney cells could be concentrated into urokinase (UK), human granulocyte conditioning factor (HGCF) and erythropoietin fractions. Human lymphocytes were inconclusive. For the isotachophoresis part of the experiment, separation of human erythrocytes from hemoglobin or dyes was achieved. Separation of human and rabbit erythrocytes or rabbit and sheep erythrocytes was not achieved.

CONCLUSIONS: With the success of separation of the standard particles, it was shown that electrophoresis can be performed under zero-g conditions. The absence of significant electro-osmosis, the loading and returning of a sterile system, the capture of the resulting separation, and the preservation of

the viable cells in orbit and during the subsequent return represents many "firsts" for space. The newer methods of separation by isotachopheresis proved the feasibility of conducting large-particle processing by this method. Unfortunately, the experiment was not totally successful because the fluid lines in some of the columns were blocked.

PUBLICATIONS: 10, 11, 12, 25, 82, 93, 463

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PRINCIPAL INVESTIGATOR(S): J. Vernon Bailey

EXPERIMENT TITLE/NUMBER: In-flight Radiation Detection

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health, Radiobiology

OBJECTIVES: To determine inflight radiation exposure.

PROTOCOL: Radiation dosimeters were worn in pockets of inflight coveralls.

EQUIPMENT: Personal Radiation Dosimeter (PRD), Passive Dosimeter (PD).

RESULTS: Five of the six dosimeters operated satisfactorily throughout the mission. Crew exposure varied from 10 to 15 mrad/day which approached the minimum response sensitivity of the PRD's. This was among the lowest exposure reported for any Apollo mission.

CONCLUSIONS: The total space radiation exposure of the ASTP crewmen was not significant.

PUBLICATIONS: 15, 16

PRINCIPAL INVESTIGATOR(S): J. Vernon Bailey

EXPERIMENT TITLE/NUMBER: Radiation Protection and Instrumentation

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human

DISCIPLINE(S): Radiobiology, Environmental health

OBJECTIVES: To study natural and man-made radiation in space and to limit astronaut exposure.

PROTOCOL: Dosimeters were placed at various locations in garments worn by the crew throughout the mission to determine accurate radiation doses for different parts of the body.

EQUIPMENT: Van Allen belt dosimeter, nuclear particle detection system, neutron resistant foil, personal radiation dosimeter.

RESULTS: Personal passive dosimeters detected 0.16 to 0.55 rads/mission on Apollo missions. An exception was on Apollo 14 when the crew was exposed to 1.14 rad.

CONCLUSIONS: Radiation was not an operational problem during the Apollo Program. Doses received by the crewmen of Apollo missions 7 through 17 were small because no major solar-particle events occurred during those missions. Solar-particle releases are random events, and it is possible that flares, with the accompanying energetic nuclear particles might hinder future flights beyond the magnetosphere of the Earth.

PUBLICATIONS: 17, 30, 37, 39, 187

PRINCIPAL INVESTIGATOR(S): J. Vernon Bailey, Rudolph A. Hoffman, and Robert A. English

EXPERIMENT TITLE/NUMBER: Radiological Protection and Medical Dosimetry for the Skylab Crewman

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Radiobiology, Environmental health

OBJECTIVES: To study radiation exposure in space.

PROTOCOL: Each crewman wore a passive dosimeter strapped on ankle or wrist. Passive dosimeters were placed in the Orbital Workshop film storage vault. Crewmen reported dosimeter readings daily.

EQUIPMENT: Passive dosimeters.

RESULTS: Personal passive dosimeters detected 1.98 to 7.81 rad/mission. Skin, eye lens and blood forming organ doses were computed from Van Allen Belt dosimeter and electron-proton spectrometer. Dose was related to length of mission:

Skin: 3.44 to 16.04 rem  
Lens: 2.72 to 11.83 rem  
Blood forming organs: 1.68 to 7.32 rem.

CONCLUSIONS: Dose equivalents for each crewman were well below the threshold of significant clinical effect. A SL crewman could fly a mission comparable to one 84-day SL4 mission per year for 50 years before exceeding career limits for radiation exposure.

PUBLICATIONS: 18, 19

PRINCIPAL INVESTIGATOR(S): Joseph T. Baker, Arnauld E. Nicogossian, G. Wyckliffe Hoffler, Robert L. Johnson, and Jerry R. Hordinsky

EXPERIMENT TITLE/NUMBER: Changes in the Achilles Tendon Reflexes Following Skylab Missions

PROGRAM/MISSION: Skylab 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal, Neurosensory

OBJECTIVES: To assess possible neuromuscular alterations following extended spaceflight by conducting measurements of the Achilles tendon reflex duration and its associated muscle potential.

PROTOCOL: Each of the crewmembers participated in 3 preflight and six postflight tests. The crewmember positioned his right knee on a firm support, with additional support as necessary to achieve relaxation of the gastrocnemius muscle. A relative displacement transducer was attached to the plantar bearing surface. Muscle potentials were taken. The Achilles tendon was struck several times as a warm up. To elicit reproducible and well inscribed tendon reflexes, the Achilles tendon was struck every two seconds for thirty seconds with a percussion hammer. No reinforcement maneuver was used to augment the reflex.

EQUIPMENT: Relative displacement transducer, silver electrodes, FM magnetic tape.

RESULTS: Crewmembers of Skylab 3 and 4 exhibited a significantly shortened reflex in the immediate postflight period. A compensatory prolongation of the reflex duration was exhibited between 4 and 12 days after recovery followed by a gradual return to the preflight values. In general, the muscle potential interval corresponded with the increase and decrease in the reflex duration.

CONCLUSIONS: The changes in reflex duration may be due to the servofeedback system of the postural muscles in which they must suddenly resume upright support of the body in a one-g environment after weeks of inactivity. An attendant strain and stretch in these muscles results in an overstimulation of the neuromuscular system causing initial decrease in reflex duration. As the muscles regain strength and mass, there occurs an overcompensation reflected by increased reflex duration. When a normal neuromuscular state is reached, the reflex duration returns to baseline value.

PUBLICATIONS: 22, 23, 24

PRINCIPAL INVESTIGATOR(S): Michael A. Bender, Frederick J. deSerres, P.  
Carolyn Gooch, I. R. Miller, D. B. Smith and Sohei  
Kondo

EXPERIMENT TITLE/NUMBER: Radiation and Zero-Gravity Effects on Human  
Leukocytes and Neurospora crassa, S004

PROGRAM/MISSION: Gemini 3, 11

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Radiobiology, Hematology, Cell Biology, Genetics

OBJECTIVES: To determine if there is any synergism between radiation and  
space flight in white blood cells, and in Neurospora crassa, and if there are  
any large radiobiological effects following space flight.

PROTOCOL: whole human blood and Neurospora crassa spores were irradiated with  
<sup>32</sup>P B-rays during orbit. Irradiation was accomplished by identical  
experimental devices, one on the righthand hatch of the spacecraft, and one on  
the ground. Upon completion, a cytogenetic analysis was made of each blood  
sample, and the frequencies of chromosome aberration determined. Yields of  
both single and multiple break aberrations were calculated for the flight and  
ground-control samples. Survival of the spores and mutability of two  
different genes were studied for frequencies of chromosome breakage and of  
gene mutation. Spore samples were irradiated on the surface of filters and in  
suspension form. Gemini 3 carried only human blood while Gemini 11 carried  
both specimens.

EQUIPMENT: <sup>32</sup>P source, aluminum blood-sample holder, dosimeter rods.

RESULTS: A synergism between radiation and some space flight parameters  
appeared to exist for human chromosome aberration production on the Gemini 3  
flight. It seems likely that this effect is on the normal restitution of  
chromosome breaks. Both the Gemini 11 blood experiment and the Neurospora  
crassa experiment failed to result in data confirmatory of the apparent  
synergism observed on the Gemini 3 mission.

CONCLUSIONS: The two parts of this experiment have shown that neither orbital  
space flight nor any of the stresses connected with it produced significant,  
unpredicted genetic damage, at least insofar as chromosomal aberration  
production is a valid measure of this general type of effect.

PUBLICATIONS: 30, 31, 32, 33, 34, 145, 149, 152

PRINCIPAL INVESTIGATOR(S): Stuart A. Bergman, G. Wyckliffe Hoffler, and Robert L. Johnson

EXPERIMENT TITLE/NUMBER: Evaluation of the Electromechanical Properties of the Cardiovascular System After Prolonged Weightlessness

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To evaluate the electromechanical properties of the cardiovascular system.

PROTOCOL: Cardiovascular electromechanical measurements were collected on all returning Skylab crewmen at rest and during both lower body negative pressure and exercise stress testing. These data were compared with averaged responses from multiple preflight tests. Systolic time intervals and first heart sound amplitude changes were measured. Clinical cardiovascular examinations included phonocardiograms, apexcardiograms, pneumograms, and carotid pulse analyses.

EQUIPMENT: Lower body negative pressure device, phonocardiographic system, vectorcardiograph, strain gage, displacement transducer.

RESULTS: In all crewmen, there were significant postflight changes in ejection time index, pre-ejection period, and in the ratio of the two. All systolic time intervals returned to preflight values within one month. There were decreases in first heart sound amplitude responses to lower body negative pressure. The systolic time interval data were consistent with a reduced stroke volume. There was a marked reduction in all heart sounds, precordial movement, and arterial pulsations.

CONCLUSIONS: The results suggest that there is a functional impairment to venous return and perhaps a myocardial factor in the overall decreased tolerance to stress in the postflight period. All changes noted returned to normal within 30 days postflight. Therefore, the processes seem transient and self-limited. The cardiovascular system seems to adapt to 0-g, and is capable of readaption to one-g after long duration space flight. Repeated exposures to 0-g also appear to have no detrimental effects on the cardiovascular system.

PUBLICATIONS: 40, 41, 42

PRINCIPAL INVESTIGATOR(S): Jeri W. Brown

EXPERIMENT TITLE/NUMBER: Crew Height Measurement

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To quantify the effects of zero-g on crewman height and to determine the change as a function of time over a mission length comparable to the projected initial Space Shuttle flights.

PROTOCOL: Sitting height and eye-level height were measured preflight, inflight and postflight.

EQUIPMENT: Tape measure.

RESULTS: Increased stature was noted. This increase occurred as a two-step "growth". Only a small change (1.3 cm average) occurred between launch and mission day 6. The major change, as much as 6.6 cm total, occurred between mission days 6 and 9.

CONCLUSIONS: The smaller initial change may result from removing g-loads on the body and thus permitting loss of spinal curvature. A similar expansion is observed on Earth when stature is compared between standing and supine body positions. The second larger "growth" may be accounted for from the expansion of the now unloaded intervertebral disks. This expansion may be further affected by the body fluid shifts in zero-g.

PUBLICATIONS: 90, 91

PRINCIPAL INVESTIGATOR(S): Lee R. Brown, William J. Frome, Sandra Handler,  
Merrill G. Wheatcroft, and Linda J. Rider

EXPERIMENT TITLE/NUMBER: Skylab Oral Health Studies

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Environmental health

OBJECTIVES: To maintain oral health.

PROTOCOL: During all missions, provision was made for an extension of the crewmen's home care program and equipment. Training was provided to all astronauts for self-treatment inflight should the need arise.

EQUIPMENT: Inflight Medical Support System Dental Kit.

RESULTS: Evaluation of Skylab crewmembers for mission-related effects on oral health in relation to possible dental injuries provided the following distinctive changes: (1) increased counts of specific anaerobic and streptococcal components; (2) elevations in levels of secretory IgA concurrent with diminutions of salivary lysozyme, and (3) increases in dental calculus and gingival inflammations.

CONCLUSIONS: The most significant finding from these investigations was the relative nonexistence of health hazardous intraoral changes. The clinical changes are considered to be more influenced by the preexisting state of dental health than by any mission-related effects.

PUBLICATIONS: 92, 93, 94

PRINCIPAL INVESTIGATOR(S): T. F. Budinger, Cornelius A. Tobias, E. Schopper, J. U. Schott, R. H. Huesman, F. T. Upham, and T. F. Weiskamp

EXPERIMENT TITLE/NUMBER: Light Flash Observations, MA-106

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Radiobiology

OBJECTIVES: To ascertain quantitatively the frequency, character, latitudinal dependence, and identity of cosmic particles that cause light flash phenomena. The ultimate objective was the assessment of radiation hazards for long-term Earth-orbiting and interplanetary missions.

PROTOCOL: Two revolutions were devoted to this experiment. During revolution 110, the silicon telescope-spectrometer was deployed for the measurement of the trajectory, atomic charge Z, and velocity of cosmic particles with a stopping power of 10 keV/micrometer or greater. During revolution 111, the Apollo commander and the Command Module pilot made continuous observations of visual sensations while dark adapted. The Docking Module pilot operated the experiment control unit, which received data from the silicon detectors as well as from silver chloride crystals that were used to register particle tracks in four sectors of the orbit corresponding to northern latitudes, equatorial latitudes, the South Atlantic Anomaly (SAA), and southern latitudes.

EQUIPMENT: Two dark adaptation masks, two pushbuttons, two cosmic-particle detector boxes, and a control and power unit that housed a data tape.

RESULTS: A total of 82 events was reported by the two astronauts. No increased activity in the SAA and no graying of the darkened visual fields occurred. The abundance of ions that caused the light flash phenomena is minimal between latitudes 30 degrees N and 30 degrees S. The frequency of light flash events between latitudes 30 degrees N and 50 degrees N and 30 degrees S and 50 degrees S is 25 times that noted in equatorial latitudes. This distribution of flashes is correlated with the distribution of cosmic particles with stopping power greater than 15 keV/micrometer in the eye.

CONCLUSIONS: The frequency of reported light flash events is strongly dependent on latitude. There was an increased rate of visual events near the south geomagnetic pole which can be explained by dark adaptation of the crewmembers. There were no reports of high frequency throughout the SAA as was expected from a previous Skylab 4 report. The flux of protons was 23 times greater for Skylab at a 443 km altitude than for Apollo-Soyuz at 225 km. The Apollo Command Module had greater radiation shielding than Skylab which allowed fewer events.

PUBLICATIONS. 108, 109, 110, 111, 112

PRINCIPAL INVESTIGATOR(S): Eduard C. Burchard, and Arnauld E. Nicogossian

EXPERIMENT TITLE/NUMBER: Achilles Tendon Reflex

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal, Neurosensory

OBJECTIVES: To measure the Achilles tendon reflex in order to detect changes in neuromuscular function.

PROC. COL: The measurement was performed during the physical examination on all three astronauts on days F-30, F-15, and on R+0. A photoelectric cell was employed to time the Achilles tendon reflex by measuring the displacement of the foot. A tap on the Achilles tendon with a percussion hammer caused the foot to move in the light beam and generate a change in photocell voltage. The changes were recorded on electrocardiograph paper to give a time-position plot of reflex action. Measurements were made from the beginning of the hammer tap to one-half the relaxation period.

EQUIPMENT: Photomotograph.

RESULTS: The ACDR and the DMP exhibited a shortening in the reflex duration time, whereas the CMP showed an increased reflex time. In addition, all crewmembers showed significant fine tremor, as documented by tracings which could reflect the effects of the inhaled vapor of nitrogen tetroxide. This tremor which was recorded on the baseline tracings of the Achilles tendon reflex was also clinically observed in the fingers for a short time on R+0.

CONCLUSIONS: The data show the predicted postflight change in the Achilles tendon reflex time. For the first time since the tendon reflex measurement was introduced, postflight tremor was documented.

PUBLICATIONS: 127

PRINCIPAL INVESTIGATOR(S): B. Sue Criswell

EXPERIMENT TITLE/NUMBER: Cellular Immune Response

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Hematology, Cell biology, Immunology

OBJECTIVES: To study the effects of spaceflight parameters on cellular immune response.

PROTOCOL: Samples of heparinized peripheral venous blood (10 cm<sup>3</sup>) were obtained and processed within one to 24 hours after collection. Before separation, total leukocyte (WBC) counts were performed using a hemacytometer and/or a Coulter counter, and differential counts were determined using slide preparations stained with Wright's stain. Parameters studied were WBC concentrations, lymphocyte numbers, B- and T-lymphocyte distributions in peripheral blood, and lymphocyte responsiveness to phytohemagglutinin (PHA), pokeweed mitogen (PWM), Concanavalin A (ConA), and influenza virus antigen.

EQUIPMENT: Venous blood collection equipment and blood storage equipment.

RESULTS: Reduced human lymphocyte response (uptake of <sup>3</sup>H thymidine) to phytohemagglutinin (PHA) was found on R+0 and R+1 but was within normal range R+8. There were varied responses to pokeweed and Concanavalin A mitogens. No quantitative T-cell, B-cell population changes were found. One of the 3 crewmen responded to influenza virus (type A) antigen postflight. The entire crew responded to England strain preflight.

CONCLUSIONS: Although the crewmen appeared to have no overt disease process upon return, they did appear to experience a stress phenomenon similar to a disease state which may have created the observed depression in lymphocytes. Because no inflight blood samples were analyzed for lymphocytic responsiveness, it is not known if the suppression begins immediately after a 9-day stay in space or is a result of splashdown stresses. Because cortisol, in high doses, is known to control the immune response, the depressions in lymphocytic responsiveness in this instance may be related to the administration of cortisol on R+0.

PUBLICATIONS: 136, 137

PRINCIPAL INVESTIGATOR(S): Lawrence F. Dietlein, and Elliott S. Harris

EXPERIMENT TITLE/NUMBER: Bioassay of Body Fluids - M005

PROGRAM/MISSION: Gemini 7, 8, 9

CLASSIFICATION: Human

DISCIPLINE(S): Hematology, Endocrinology

OBJECTIVES: To determine the metabolic cost of manned spaceflight and to use the results to indicate the physiological status of the crewmembers.

PROTOCOL: Samples taken pre- and postflight of plasma/serum were assayed for 17-hydroxycorticosteroids, proteins, antidiuretic hormone, hydroxyproline, electrolytes, bilirubin, and uric acid. Pre-, post-, and inflight samples of urine were assayed for volume, specific gravity, osmolality, pH, 17-hydroxycorticosteroids, electrolytes, catecholamines, nitrogenous compounds, antidiuretic hormone and aldosterone. Plasma was taken immediately after recovery, and at R+6, 24, and 72 hours. Urine was collected continuously for 48 hours after flight.

EQUIPMENT: Assay equipment and urine collection device.

RESULTS: Electrophoretic patterns were normal. There was an increase in 17-hydroxycorticosteroids immediately after recovery, which returned to normal within 6 hours. There was a drop in plasma uric acid, which may have been caused by low purine intake. There was marked water retention immediately postflight and retention of electrolytes. This is consistent with the hypothesis that atrial and thoracic stretch receptors are of physiological importance in gravity change.

CONCLUSIONS: Electrolyte and water retention observed immediately postflight are consistent with the assumption that the Gauer-Henry atrial reflex was responsive to a change from the weightless to the one-g environment. Alterations in electrolyte and water distribution during the flight may have been contributory. Immediately postflight, plasma 17-hydroxycorticosteroid levels were elevated. Plasma uric acid was reduced. The cause of the reduction is unknown, but is presumed to be dietary.

PUBLICATIONS: 154, 155, 163, 249

PRINCIPAL INVESTIGATOR(S): Lawrence F. Dietlein, and William V. Judy

EXPERIMENT TITLE/NUMBER: Cardiovascular Conditioning, MO01

PROGRAM/MISSION: Gerini 5, 7

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To prevent cardiovascular deconditioning.

PROTOCOL: Pneumatic cycling system alternately inflated and deflated leg cuffs attached to pilot's thighs. Prior to the mission, each crewmember was given a series of tilt-table tests as a control.

EQUIPMENT: Pressurized storage vessel charged with oxygen to 3,500 psig, a pneumatic control system for monitoring the pressurized storage vessel, a pneumatic oscillator system for periodically inflating and deflating the leg cuffs.

RESULTS: Preflight tilt (70° upright) showed increased heart rate, diastolic pressure, and leg volume. Postflight tilt (R+0) showed large increases in heart rate, leg volume, decreases in systolic, diastolic and pulse pressures. Effects were less pronounced R+1 and R+3. Pretilt leg volume at R+3 was still elevated.

CONCLUSIONS: Venous leg cuffs were not effective in reducing postflight orthostatic intolerance for the crewmen who wore them in flight. The pulsatile cuffs appeared to be effective in lessening the degree of postflight pooling of blood in the lower extremities as judged by the strain gage technique.

PUBLICATIONS: 156, 157, 160, 169, 460

PRINCIPAL INVESTIGATOR(S): Lawrence F. Dietlein, and Rita M. Rapp

EXPERIMENT TITLE/NUMBER: Inflight Exercise and Work Tolerance, M003

PROGRAM/MISSION: Gemini 4, 5, 7

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular, Respiratory, Behavioral science

OBJECTIVES: The day-to-day evaluation of the general physical condition of the crewmembers during long-duration space flight. The basis of this evaluation was the response of the cardiovascular system to a calibrated workload.

PROTOCOL: Exercise methods with the exercise device lasted for 30 seconds during which time the astronaut stretched the bungee cords through a full extension once per second. Exercise periods were scheduled twice daily for each crewmember. Blood pressure measurements were obtained before and after each exercise period.

EQUIPMENT: A pair of rubber bungee cords attached to a nylon handle at one end and to a nylon foot strap at the other, magnetic tape recorder, and phonocardiographic system.

RESULTS: Inflight and postflight measurements were not significantly different. Postflight evaluation showed oxygen consumption and systolic blood pressure reduced. Diastolic blood pressure and pulse pressure were increased. Little change in heart rate response was found.

CONCLUSIONS: The response of the cardiovascular system to a calibrated workload is relatively constant for an individual during flight. The crewmembers are able to perform mild-to-moderate amounts of work under the conditions of space flight. No decrement in the physical condition of the crew was apparent.

PUBLICATIONS: 161, 164, 165, 460

PRINCIPAL INVESTIGATOR(S): Lawrence F. Dietlein, and Carlos Vallbona

EXPERIMENT TITLE/NUMBER: Inflight Phonocardiogram, M004

PROGRAM/MISSION: Gemini 4, 5

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To measure and correlate the various phases of electrical and mechanical activity of the cardiac cycle in order to gain insight into the cardiac functional status of crewmembers during prolonged spaceflight.

PROTOCOL: An electrocardiogram and phonocardiogram of each crewmember were recorded throughout the mission. Recording occurred in two periods. The initial period was continuous for 9 minutes, starting at 1 minute before liftoff until orbital insertion. The final period was continuous from 5 minutes before reentry until splashdown. Also, 1 minute records were made at hourly intervals, for the first 24 hours and at 4 hour intervals for the remainder of the mission until 5 minutes before reentry.

EQUIPMENT: Phonocardiographic transducer, an electrocardiographic signal transducer and onboard biomedical tape recorder.

RESULTS: Inflight rare premature atrial and ventricular contractions were found. Fluctuations of electromechanical systole duration correlated with heart rate. There were stable values for electromechanical delay. Peak heart rates occurred during launch and reentry. They were lower and stable inflight. The postflight rate was 18-62% higher than preflight.

CONCLUSIONS: Wide fluctuations in the duration of cardiac cycle were noted throughout the missions. Fluctuations in the duration of electromechanical systole that correlated with changes in heart rate and stable values for electromechanical delay were observed. There was evidence of adrenergic reaction at lift-off, during entry, and in the few hours that preceded entry.

PUBLICATIONS: 82, 158, 159, 162, 166, 167, 168, 460, 532

PRINCIPAL INVESTIGATOR(S): James K. Ferguson, Gary W. McCollum, and Benjamin L. Portnoy

EXPERIMENT TITLE/NUMBER: Analysis of the Skylab Flight Crew Health Stabilization Program

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To reduce the probability that a crewman would come into contact with an infectious disease agent during the critical time periods of each mission.

PROTOCOL: Isolation periods were established prior to launch, as well as postflight, in order to reduce the number of infectious illness contacts between crewmen. The number of personal contacts with the crewmen was limited, and ill persons were not permitted to enter primary work areas. Initially, all persons who required contact with the flight crewmen during a 21-day period before flight were identified. Physical examinations and immunizations were given to the identified personnel. Voluntary reporting and active surveillance were used to detect illness occurrences and exposures to illness among the primary contact personnel. A 7-day postflight isolation period was added to protect the crewmen from any increased susceptibility to infectious diseases.

EQUIPMENT: None identified.

RESULTS: The most frequently reported illness contacts were upper respiratory infections. Enteric illnesses were the next most common illness, but these were relatively rare compared to upper respiratory infections. The results indicate that the Flight Crew Health Stabilization Program successfully accomplished its goal in reducing the number of illness exposures to flight crewmen.

CONCLUSIONS: The effort made to reduce the number of primary contacts was of greatest importance to the goals of the program. Limiting crew contact to a defined and medically controlled population of primary contacts should be continued in future programs.

PUBLICATIONS: 189, 190

PRINCIPAL INVESTIGATOR(S): James K. Ferguson

EXPERIMENT TITLE/NUMBER: Flight Crew Health Stabilization Program

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To reduce the probability of illness in flight crewmen.

PROTOCOL: Prime and backup crewmen were held under conditions of semi-isolation from 21 days before flight until launch. An identification list of primary contacts was available to the Medical Surveillance Office 90 days before lift-off.

EQUIPMENT: None identified.

RESULTS: The rate of illnesses reported by the primary contacts was 12.4 illnesses per 1000 persons per week. The rate of contacts to illness reported was 3 per 1000 persons per week. No infectious illness occurred in any of the crewmen during the period of time they were covered by the program.

CONCLUSIONS: The rate of primary contact reporting of illnesses appeared to be improved over past missions.

PUBLICATIONS: 191

**PRINCIPAL INVESTIGATOR(S):** James K. Ferguson, Gerald R. Taylor, and Bernard J. Mieszkuc

**EXPERIMENT TITLE/NUMBER:** Microbiological Investigations

**PROGRAM/MISSION:** Apollo

**CLASSIFICATION:** Human/Microorganism

**DISCIPLINE(S):** Environmental health

**OBJECTIVES:** To detect potentially pathogenic microorganisms so that associated medical problems could be identified early and preventive measures established, to identify medically important microorganisms recovered from crewmen to aid in diagnosis and treatment, to collect microbiological data that would aid in elucidating the response of crew microbial autoflora to the space flight environment, and to evaluate the resultant effect on the crewmember.

**PROTOCOL:** Back-up and flight crews were sampled on F-30, F-14, F-0, R+0 days. Samples were taken from seven body surface sites, nose, throat and mouth, urine and feces. They were maintained at 4 degrees C during transport. TSB (Trypticase soy broth) was used for aerobic analysis and VIB (veal infusion broth) for anerobic analysis. The spacecraft was also analyzed pre- and postflight. Swab samples were taken from the mouthpiece of the drink gun, pistol grips of the CMP maneuver controller, head struts, floor beneath the foot of the center couch using Ca alginate swabs. The samples were vortexed and serially diluted, plated, and incubated at 35 degrees C.

**EQUIPMENT:** Culturing material, swabs.

**RESULTS:** Approximately 4,000 microbial isolations were obtained, identified, and characterized. Variation occurred in microbial response because of ecological relationships (e.g., fungi controlling Candida albicans decreased inflight), host susceptibility, and external environmental factors. Spread of pathogens between crewmen was common. Preflight Command Module microorganisms were replaced by crew microorganisms during flight.

**CONCLUSIONS:** Spacecraft environment did not predispose crew to viral or mycoplasma induced illness.

**PUBLICATIONS:** 192, 502, 516

PRINCIPAL INVESTIGATOR(S): Jimmie L. Flume

EXPERIMENT TITLE/NUMBER: Effect of Space Flight on the in vitro Combining Capacity of Antigen and Antibody

PROGRAM/MISSION: Discoverer XVII

CLASSIFICATION: Human, Animal

DISCIPLINE(S): Cell biology, Hematology, Radiobiology

OBJECTIVES: To determine the specific reactivity between antigens and antibodies during spaceflight.

PROTOCOL: Samples of human gamma globulin and rabbit antiserum specific for human gamma globulin were dried on small squares of filter paper and mounted on both emulsion surfaces of nuclear track plates. The squares were immobilized by means of a thin Lucite plate and the entire package wrapped in black covering. On recovery, materials were eluted from the paper in saline and reactivity was determined by means of passive hemagglutination.

EQUIPMENT: Millipore filter paper, nuclear emulsion tracking plates, black wrapping, thin Lucite plates, chemical dosimeters, alanine, albumin, silver phosphate glass rods, neutron sensitive film, antimony foil.

RESULTS: The only effect observed was an increase in reactivity in both antigen and antibody in the flight package.

CONCLUSIONS: The occurrence of greater reactivity is not understood, but it may be that sub-inhibitory concentrations of cosmic radiation may have a stimulatory effect on protein reactivity.

PUBLICATIONS: 198

PRINCIPAL INVESTIGATOR(S): James D. Frost, William H. Shumate, Joseph G. Selamy, and Cletis R. Booher

EXPERIMENT TITLE/NUMBER: Sleep Monitoring on Skylab, M133

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Neurosensory, Behavioral science

OBJECTIVES: To obtain the first objective evaluation of man's ability to sleep during extended space travel.

PROTOCOL: One of the astronauts from each mission wore a fitted cap during his sleep periods containing electrodes for EEG measurements of brain waves, accelerometers to record motions of the head, and with electrodes near one eye to sense REM sleep. Signals from these sensors, recorded on magnetic tape and analyzed after return to Earth, permitted conclusions regarding the depth and length of the sleep stages. The data collected were preflight EEG and EOG data of the crewman for three consecutive nights of sleep, periodical inflight EEG and EOG data throughout the crewman's sleep period, and postflight sleep EEG's and EOG's on approximately the 1st, 3rd, and 5th day after recovery.

EQUIPMENT: Electroencephalographic equipment, electro-oculographic equipment, elastic recording cap.

RESULTS: Analysis of EEG, EOG, and head movement showed no major changes in sleep characteristics. None of the crewmen complained excessively of sleeping difficulties.

CONCLUSIONS: These findings suggest that men are able to obtain adequate sleep in regularly scheduled 8-hour rest periods during extended space flights. The alterations in sleep patterns which were observed during these missions were not of the type, nor of sufficient magnitude (with the possible exception of the initial portion of the 84-day mission), to result in significant degradation of performance capability. Alterations seen postflight were those of sleep quality and not quantity.

PUBLICATIONS: 202, 203, 204, 205, 206, 207, 208

PRINCIPAL INVESTIGATOR(S): Owen K. Garriott, and Gary L. Dcerre

EXPERIMENT TITLE/NUMBER: Crew Efficiency on First Exposure to Zero-Gravity

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Behavioral science

OBJECTIVES: To determine the effects of zero-g on crew efficiency.

PROTOCOL: The many work tasks accomplished by each of the three Skylab crews in their early activation phase were identified and their respective performance times estimated. These work performances were compared with preflight estimates of the rate at which work would be done, with crew output later in the mission when adaptation was complete, and when the crewmembers were experienced in zero-g conditions. The very substantial amount of work devoted to repair tasks during the early mission days was also included.

EQUIPMENT: None identified.

RESULTS: It was found that on only two of of the nine full or partial activation days was the crew output significantly reduced. On the day of lowest efficiency, mission day 2 of the Skylab 3 mission, it appeared that the crewmen were working at about 75% of their "normal" efficiency and may have lost about 7 man-hours of work. Overall, a nearly constant level of work was achieved on these activation days. However, as crew proficiency improved later in the missions, the daily crew work output increased from a 26 man-hour/day to at least a 34 man-hour/day.

CONCLUSIONS: A relatively modest amount of crew time may have been lost due to motion sickness on Skylab missions 3 and 4 but each crew's performance was never substantially impaired for more than one day. During the three activation intervals, less than 12 man-hours were lost to reduced efficiency while almost 200 man-hours of productive work were delivered. Work rate improved for tasks in which simulation and training time were extensive and for tasks which allowed zero-gravity operations to be optimized.

PUBLICATIONS: 209, 210

PRINCIPAL INVESTIGATOR(S): Ashton M. Graybiel, and Earl F. Miller

EXPERIMENT TITLE/NUMBER: Human Otolith Function, M009

PROGRAM/MISSION: Gemini 5, 7

CLASSIFICATION: Human

DISCIPLINE(S): Neurosensory

OBJECTIVES: To obtain information concerning human otolith function in conjunction with exposure to orbital space flight.

PROTOCOL: There was preflight testing of ocular counterrolling (CR) and egocentric visual localization of the horizontal (EVLH) at 19 and 6 weeks before flight. Both were tested inflight. During the tests, readings of blood pressure, pulse rate, and electrocardiogram were made.

EQUIPMENT: Onboard vision tester (a binocular instrument with an adjustable interpupillary distance with no focusing adjustment).

RESULTS: There were insignificant negative deviations of 10 degrees to 30 degrees from absolute horizontal for EVLH measurements. There was no change in ocular counterrolling pre- to postflight with body tilt from -50 degrees to + 50 degrees.

CONCLUSIONS: There is no significant change in otolith sensitivity as a result of space flight. A coordinate space sense exists even in weightlessness if contact cues are adequate.

PUBLICATIONS: 76, 80, 218, 219, 221, 223, 225, 399, 550

PRINCIPAL INVESTIGATOR(S): Ashton M. Graybiel, Earl F. Miller, and Jerry L. Homick

EXPERIMENT TITLE/NUMBER: Human Vestibular Function, M131

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Neurosensory

OBJECTIVES: The three parts of this experiment were designed to determine susceptibility to motion sickness, thresholds for perception of angular acceleration as revealed by the oculogyral illusion, and the perceived direction of internal and external space.

PROTOCOL: The test parameters on the rotating litter chair were:

- 1) 0 rpm or constant rpm at varied rates (10-30 rpm)
- 2) Clockwise, counterclockwise
- 3) Front, back, right and left head movements
- 4) Selected mission days beginning day 5, 6 or 7
- 5) Eyes closed

For oculogyral illusion (rotating litter chair and visual tracking of a line target within goggles) the parameters were:

- 1) Steps of constant angular acceleration from  $0.02^{\circ}/S^2$  to  $3.0^{\circ}/S^2$
- 2) Steps of constant velocity

The stationary litter chair and goggles were used for pitch and roll parameters. Measurement of postural equilibrium was determined by standing on rails of random width during preflight and postflight tests.

EQUIPMENT: Rotating litter chair, drive motor for chair rotation, control console, otolith test goggle, custom bite boards, reference sphere and magnetic pointer with readout device, balance rails.

RESULTS: During rotation on litter chair, moderate to severe malaise (nausea) was observed preflight and postflight for specific parameter combinations. Modest malaise (epigastric discomfort, pallor) was observed inflight on the crewmen of Skylab 2, disappearing immediately after the test. Slight malaise (headache, flushing, dizziness) was observed inflight SL-3 (on 2 of 3 crewmen) disappearing immediately after test. No symptomology was observed on Skylab 4. No significant changes preflight, inflight, and postflight were found in perception of oculogyral illusion. Crewmen experienced drowsiness inflight, but not preflight or postflight. No significant changes were found preflight, inflight, and postflight in perception of pitch and roll. When testing for postural equilibrium with eyes open, there was moderate postflight decrement in 3 crewmen. For eyes closed, all crewmen showed postflight decrement, most marked R+1. Recovery was essentially complete by R+11.

CONCLUSIONS: From the standpoint of vestibular organs, the "basic" susceptibility to motion sickness is lower in weightlessness than under terrestrial conditions. Prevention of motion sickness in any stressful motion environment involves selection, adaptation, and the use of drugs. There appeared to be no inflight inhibitory influences reducing the effective "sensitivity" of the semicircular canals.

PUBLICATIONS: 216, 217, 220, 222, 224, 400

PRINCIPAL INVESTIGATOR(S): K. Hanning, and H. Wirth

EXPERIMENT TITLE/NUMBER: Electrophoresis Experiment, MA-014

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human, Animal

DISCIPLINE(S): Cell Biology

OBJECTIVES: To investigate and evaluate the increase in sample flow rate and sample resolution achievable in space.

PROTOCOL: The apparatus functioned automatically, requiring minimal crew intervention. Samples of rat bone marrow cells, spleen cells, lymph node cells with the addition of human erythrocytes as markers and a mixture of human and rabbit erythrocytes were studied. It was not necessary to collect the separated biomaterial fractions. An optoelectronic analysis of the separation was performed. A preparative separation was not used. A qualitative evaluation (by use of an optical system) was sufficient to determine the applicability of the method and to study the sharpness of separation.

EQUIPMENT: Separation chamber consisting of two cooling plates. Electrodes provided the electric field.

RESULTS: The experiment lasted for one Earth orbit. The optical system produced a light that was too bright to discern true cell distributions, but final analysis of scientific data by computer processing showed the expected distribution of separated cells.

CONCLUSIONS: The applicability of free-flow electrophoresis under zero-g conditions was confirmed. The technical problems arising from the special environmental conditions in a Spacelab can be controlled. It was demonstrated that the buffer flow systems operated despite the more difficult conditions imposed by a closed system. The effective removal of gases from the electrode buffer by the measures used was a necessary part of the experiment. The possibility of separating living cells under zero-g conditions was demonstrated. The cell aggregations that formed in the cell suspensions need not correspond to a decrease in viability.

PUBLICATIONS: 244, 245, 246 247

PRINCIPAL INVESTIGATOR(S): W. Royce Hawkins, and John F. Zieglschmid

EXPERIMENT TITLE/NUMBER: Clinical Aspects of Crew Health

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To insure crew safety from a medical standpoint, insure sufficient medical information for management decisions, prevent back-contamination from the lunar surface, and further the understanding of biomedical changes incident to space flight.

PROTOCOL: Preflight medical screening and examination, health stabilization, drug sensitivity testing, medical training, inflight biotelemetry, diagnosis and treatment, and post-flight physical examinations were performed.

EQUIPMENT: Biosensor harness, Biobelt assembly, EKG, cardiometer, impedance pneumograph, medical kit.

RESULTS: Apollo crews reported cephalad fluid shifts, soreness of back muscles, insomnia, and motion sickness. Postflight resting and stressed heart rates were elevated in almost all crewmen, heart size was decreased approximately five percent, and there was some degree of cardiovascular deconditioning, reduction of red blood cell mass, and musculoskeletal deterioration.

CONCLUSIONS: The Apollo astronauts did not encounter any major medical problems. Those physiological changes which did occur were all reversible within a two to three day period postflight with the exception of the Apollo 15 crew. It took two weeks for them to completely return to preflight baselines. A sound medical basis existed for committing man to the prolonged space flight exposure to Skylab.

PUBLICATIONS: 82, 251, 460

PRINCIPAL INVESTIGATOR(S): Walter L. Henry, Stephen E. Epstein, James M. Griffith, Robert E. Goldstein, and David R. Redwood

EXPERIMENT TITLE/NUMBER: Effect of Prolonged Space Flight on Cardiac Function and Dimensions

PROGRAM/MISSION: Skylab 4

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To determine the effect of prolonged spaceflight on cardiac function and dimension.

PROTOCOL: The T-scan technique was used to measure thickness of the ventricular system and posterobasal left ventricular wall. Stroke volume was calculated by subtracting the end-systolic volume from the end-diastolic volume while ejection fraction was determined by dividing stroke volume by end-diastolic volume. Measurements were performed 10 days before launch, on recovery day and 1, 2, 4, 11, 31 and 68 days postflight. They were made in conjunction with the lower body negative pressure protocol.

EQUIPMENT: Echocardiograph.

RESULTS: Small but significant decreases in stroke volume occurred in two of the three astronauts. No significant alteration in cardiac function occurred in any astronaut. The small decreases in left ventricular end-diastolic volume, stroke volume and left ventricular mass were reversible postflight over a 30-day period.

CONCLUSIONS: There was no deterioration in cardiac function. The cardiovascular system adapts well to prolonged weightlessness and, therefore, alterations in cardiac dimensions and function are unlikely to limit man's future in space.

PUBLICATIONS: 265, 266

PRINCIPAL INVESTIGATOR(S): Peter W. Higgins, Joseph C. Lill, and Timothy T. White

EXPERIMENT TITLE/NUMBER: Radiation Environment at High Orbital Altitudes

PROGRAM/MISSION: Gemini 10, 11

CLASSIFICATION: Human

DISCIPLINE(S): Radiobiology

OBJECTIVES: To measure the radiation environment and its effects in the South Atlantic Anomaly (SAA).

PROTOCOL: Radiation dose calculations were made by determining the radiation environment within the spacecraft and its effects on the crew using a radiation monitoring system and passive dosimeters.

EQUIPMENT: Radiation monitoring system, passive dosimeters.

RESULTS: An increase in dose was found in Gemini 10 high-altitude passes through the SAA with negligible doses received on Gemini 11 after a much higher altitude flight opposite the SAA.

CONCLUSIONS: Manned spaceflight at higher altitudes was possible with a minimum of radiation dose. This was due to the confirmed continuing decay of the artificially injected electrons and to careful planning of the trajectory.

PUBLICATIONS: 269

PRINCIPAL INVESTIGATOR(S): G. Wyckliffe Hoffler, and Robert L. Johnson

EXPERIMENT TITLE/NUMBER: Apollo Flight Crew Cardiovascular Evaluations

PROGRAM/MISSION: Apollo 7-9, 15-17

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To determine the response of the cardiovascular system to weightlessness.

PROTOCOL: Lower body negative pressure (LBNP) was used, with 5 minutes rest, 15 minutes reduced pressure, and 5 minutes recovery, using 3 different pressure levels. There was also a passive test of 5 minutes resting supine and 5 minutes passive standing. Ambient temperature and oral temperature were recorded pre- and postflight for orthostatic evaluations. Physiological measurements were recorded in real time on strip chart recording, and FM magnetic tape.

EQUIPMENT: LBNP device, antihypotension garment, electrocardiograph, thermometers, physiological sensors.

RESULTS: The resting supine heart rate was elevated significantly in 54% of the crewmen on the first day postflight. Application of -50mm Hg LBNP elevated the rate in 82%. The Apollo 15 LMP experienced presyncope during the last second of -40mm Hg, while the Apollo 8 CMP and LMP, Apollo 9 LMP, Apollo 16 LMP and CMP all developed presyncope during the -50mm Hg level of LBNP. The passive standing test had the same elevated heart rate results. There was also a significant decrease in the systolic and pulse pressure during LBNP in the first postflight evaluation. There was a significant decrease in weight postflight.

CONCLUSIONS: Postflight orthostatic evaluations during the Apollo program indicated that reduction in orthostatic tolerance is a consequence of space flight exposure. Heart rate, the most reliable index, was increased, while systolic and pulse pressures were decreased during immediate postflight evaluations using lower body negative pressure and passive standing as the orthostatic stress. Postflight changes in leg volume during LBNP were equal to or less than those seen during preflight baseline evaluations. Body weight, resting calf girth, supine leg volume, and cardiothoracic ratios were all diminished immediately postflight, and return to preflight values was not complete within the postflight testing time frame. The wearing of a lower body positive pressure garment during the reentry and immediate postflight period offered some protective benefit by way of reducing lower body pooling of fluid.

PUBLICATIONS: 78, 82, 270, 271, 460

**PRINCIPAL INVESTIGATOR(S):** G. Wyckliffe Hooper, Arnauld E. Nicogossian,  
Stuart A. Bergman, and Robert L. Johnson

**EXPERIMENT TITLE/NUMBER:** Cardiovascular Evaluations

**PROGRAM/MISSION:** Apollo-Soyuz Test Project

**CLASSIFICATION:** Human

**DISCIPLINE(S):** Cardiovascular

**OBJECTIVES:** To determine the response of the cardiovascular system to weightlessness.

**PROTOCOL:** Preflight: orthostatic tolerance test by LBNP, heart size measurement by chest X-rays, resting leg volume measurement, echocardiogram. Postflight: LBNP, chest X-rays, leg volume.

**EQUIPMENT:** Echocardiograph, LBNP device, vectorcardiograph, X-rays.

**RESULTS:** No results could be considered unusually aberrant; only a single episode of presyncope occurred. Because LBNP recordings made immediately after flight were deleted, no useful information was obtained from systolic time intervals, vectorcardiograms, or echocardiograms.

**CONCLUSIONS:** Findings did not differ from those resulting from previous U. S. manned space missions: a modest postflight decrement in orthostatic tolerance without operational significance was demonstrated. The inflight leg volume data augment those from the Skylab 4 mission and elaborate further on the early inflight period.

**PUBLICATIONS:** 272

PRINCIPAL INVESTIGATOR(S): G. Wyckliffe Hoffler, Stuart A. Bergman, and  
Arnauld E. Nicogossian

EXPERIMENT TITLE/NUMBER: In-Flight Lower Limb Volume Measurement

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To substantiate with further data, the volume decrement that occurs inflight, to obtain earlier inflight volume determinations and to document the time course of headward fluid shifts by frequent serial leg volume measurements.

PROTOCOL: During the period from day F-45 to day F-1, five independent determinations of the left leg volume were made. Crewmembers were instructed and trained in the procedure and actually conducted the F-1 measurements on themselves to ensure adequate familiarization for their seven inflight measurement sessions. Right leg measurements were obtained three times before flight and once on recovery day (R+0) by medical team personnel. Because of circumstances associated with the toxic nitrogen tetroxide gas event during the recovery period, leg volumes were not obtained beyond the fourth postflight day (R+4).

EQUIPMENT: Limb Volume Measuring Kit.

RESULTS: Decreasing leg size as the launch period approached is in accordance with preflight findings from previous flight crews. All inflight volumes dropped below the lower 95% confidence limit established by preflight volumes. Earliest postflight determinations were taken between 1.5 and 2 hours after splashdown. Leg volumes on all three crewmen increased well above their last inflight values. Second measurements on recovery day, some 2 to 5 hours after splashdown, showed even greater leg volumes in accordance with the reversing effects of readaptation in normal gravity.

CONCLUSIONS: Several of the oscillatory variations observed in ASTP flight crewmembers may be judged to be actual physiologic damping responses. With a single datum for inference, it appears that the major shift of fluid volume from the legs does not occur in the first few hours of orbital exposure. The course seems more likely to assume an exponential form with maximal rate of decrement within the first 24 hours. A distinct plateau is evident by 3 to 5 days with little significant additional decrease occurring after the first week in weightlessness. These fluid volume shifts coincide with the occurrence of major crew symptomatology and the plateau with relative adaptive stability.

PUBLICATIONS: 273

PRINCIPAL INVESTIGATOR(S): G. Wycliffe Hoffler, Robert L. Johnson, Arnauld E. Nicogossian, Stuart A. Bergman, and Margaret M. Jackson

EXPERIMENT TITLE/NUMBER: Vectorcardiographic Results from M092

PROGRAM/MISSION: Skylab

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To determine the degree and the time course of cardiovascular adaptation under zero-gravity conditions.

PROTOCOL: Vectorcardiograms were recorded via a modified Frank lead system on all crewmen of the three Skylab missions in conjunction with the Lower Body Negative Pressure experiment. Data were analyzed by a specially developed computer program (VECTAN). Design of the test sequences allowed direct comparisons of supine resting, Earth based (reference) vectorcardiograms with those taken during lower body negative pressure stress and those obtained at rest in orbit, as well as combinations of these conditions.

EQUIPMENT: Lower Body Negative Pressure Device, vectorcardiograph.

RESULTS: No adverse vectorcardiographic changes occurred during flight. Analysis of inflight measurements showed significantly increased PR interval, QT interval, QRS maximum vector magnitude, QRS-Eigenloop vector magnitude, and QRS-T angle. Recovery measurements (R+0) showed significantly elevated vector magnitudes for QRS maximum, QRS-Eigenloop and T. Other parameters measured (QRS duration, QT interval, P maximum vector magnitude, ST maximum vector magnitude, ST slope) were not significantly changed inflight or postflight.

CONCLUSIONS: Vectorcardiograms have shown several consistent changes apparently related to space flight. There were changes in temporal intervals, vector magnitudes and their orientations, and certain derived parameters, presumably as a consequence of altered autonomic neural inputs upon the myocardial conduction system and/or of major fluid shifts known to have occurred inflight. All observed measurements were well within accepted normal limits and are considered to represent adaptive phenomena rather than pathological conditions.

PUBLICATIONS: 211, 274, 275

PRINCIPAL INVESTIGATOR(S): Rudolph A. Hoffman, Lawrence S. Pinsky, W. Zach Osborne, and J. Vernon Bailey

EXPERIMENT TITLE/NUMBER: Visual Light Flash Observations on Skylab 4

PROGRAM/MISSION: Skylab 4

CLASSIFICATION: Human

DISCIPLINE(S): Radiobiology

OBJECTIVES: To investigate the frequency and character of visual light flashes in near Earth orbit as the Skylab trajectory passed from northern to southern latitudes. Because the trajectory periodically passed through the South Atlantic Anomaly (SAA), another objective was the investigation of possible visual flashes during passage through this region.

PROTOCOL: Two separate light flash observation sessions were performed on mission days 74 and 81 by the pilot. The first session occurred during an orbit that allowed observations from high geomagnetic latitudes. The orbit for the other session passed through the center of the SAA. The pilot got into his sleep restraint, set a timer for either 55 or 70 minutes, donned a blindfold and recorded his observations of flashes on the voice recorder. Ten minutes were allowed for dark adaptation.

EQUIPMENT: Voice recorder, blindfold.

RESULTS: A total of 168 flashes was reported: 24 during the first session and 144 during the second. Three to nine flashes/minute were observed. The frequency was related to latitude, the highest being in the SAA and the lowest over the poles.

CONCLUSIONS: There is a strong correlation of very high flash rates with passage through the SAA, and from physical arguments and event descriptions it appears certain that these flashes are due to trapped radiation. There is evidence for the predicted latitude effect, although existing data are insufficient for a thorough statistical evaluation. A greater particle flux in the trajectory through the SAA probably explains the increased number of flashes observed at that time, but there were also more flashes observed outside the anomaly during the second period where the cosmic particle environment should have been comparable. This variation remains unexplained. There may be particles heavier than protons in the inner belt of trapped radiation of the SAA.

PUBLICATIONS: 276, 277, 413, 428

PRINCIPAL INVESTIGATOR(S): Jerry L. Homick, and Earl F. Miller

EXPERIMENT TITLE/NUMBER: Apollo Flight Crew Vestibular Assessment

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human

DISCIPLINE(S): Neurosensory, Behavioral science

OBJECTIVES: To observe the effects of space flight on the human vestibular system.

PROTOCOL: Motion sickness history files were compiled on each astronaut. No systematic program to quantitatively assess the effects of space flight on crew vestibular function was pursued prior to Apollo 16. For the last two Apollo missions, postural equilibrium was tested by a modified standard lab method with crewmen balancing on four rails of different widths plus the floor. There was a tape for foot alignment on the floor. Time, the performance measure of balance, began when the crewmen, while standing on the prescribed support with his feet in a tandem heel-to-toe arrangement, folded his arms. The test was made with eyes open, then closed. Nystagmus was measured with the aid of recording electrodes placed around the eyes. Caloric irrigation complemented tests of balance by monitoring change in semicircular canal activity. Irrigating temperatures were 34.0 degrees C and 35.5 degrees C. Tests were taken for Apollo 16 on F-30, R+3, and R+7, and for Apollo 17 on F-30 and F-15 and none postflight.

EQUIPMENT: Electronystagmograph, postural equilibrium rails.

RESULTS: Eleven of the 33 individuals who have flown on Apollo flights have experienced apparent vestibular difficulties. Of these eleven, nine had positive motion sickness histories. Conversely, 18 of 27 individuals with positive histories had no inflight symptomatology. Six of the eleven crewmen with inflight problems experienced minor symptoms, two experienced moderate symptoms, and three had severe symptomatology. It is questionable whether the vomiting experienced by one of these latter individuals was vestibular in origin or due primarily to gastroenteritis. Six (40 percent) of the 15 individuals making their first space flight developed inflight symptoms. Of the 18 veteran pilots, only five (approximately 28 percent) experienced symptoms.

For the Apollo 16 crew, during the first (R+3) and second (R+7) postflight test periods, postural equilibrium with eyes open was nearly identical to preflight performance for all crewmen. The CDR actually demonstrated a slight progressive improvement on this task with time. At R+3, however, the CDR and the CMP exhibited a marked decrease in postural stability when deprived of all visual sensory cues. When these two individuals were tested again at R+7, there was a definite improvement in postural stability with eyes closed

compared to their R+3 performance. The CMP improved his preflight, eyes-closed scores, whereas the performance of the CDR was approximately midway between his two previous scores. The caloric irrigation test revealed increased nystagmus activity on R+3 in the CDR and to a lesser extent in the CMP. Responses on both tests were near baseline values by R+7.

CONCLUSIONS: Increased mobility and thus increased head movements as afforded by the larger volume of the Apollo CM/LM, resulted in a higher incidence of vestibular disturbances in the Apollo Program than in previous programs. In most cases in which symptoms did occur, they were mild to moderate and could be controlled by limiting head movements the first few days in flight. Adaptation of the vestibular receptors to the weightless environment apparently occurred within the first several days of flight for most individuals. Extravehicular activity in one-sixth-g on the lunar surface resulted in no disorientation or vestibular disturbances. Apparently, one-sixth-g is an adequate stimulus for the otolith organs to provide sensory information regarding gravitational upright and, hence, maintenance of posture. With an important exception of the Apollo 15 mission, no crewmen experienced pronounced vestibular disturbances after returning from space flight. This finding suggests that adaptive processes that occur during weightless space flight missions of up to two weeks in duration do not render the vestibular system significantly hyposensitive or hypersensitive following sudden return to a one-g environment. Vestibular problems cannot be predicted reliably from previous history of motion sickness. However, astronauts making their first space flight appear to be slightly more susceptible to the development of inflight symptoms than are experienced astronauts.

PUBLICATIONS: 278

PRINCIPAL INVESTIGATOR(S): Jerry L. Homick, Millard F. Reschke, and Earl F. Miller

EXPERIMENT TITLE/NUMBER: The Effects of Prolonged Exposure to Weightlessness on Postural Equilibrium

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Neurosensory, Behavioral science

OBJECTIVES: To assess the postural equilibrium of the Skylab astronauts following their return to a 1-g environment and to suggest possible mechanisms involved in any measured changes.

PROTOCOL: Postural equilibrium was evaluated using a modified version of a quantitative ataxia test developed by Graybiel and Fregley. The test employed a series of narrow metal rails of varying widths on which the crewman was required to maintain an upright position with his feet tandemly aligned and arms folded across his chest. Performance for this test was measured under two conditions. In the first test, the crewman kept his eyes open, and in the second, he tried to balance with his eyes closed. In both cases, performance was scored in terms of time on the rail before losing balance. Preflight baseline data were obtained on three separate occasions for each of the crewmen.

EQUIPMENT: Postural test rails.

RESULTS: There was a moderate postflight decrement in crewmen for the eyes open test. The postflight decrement was considerable for the eyes closed test which was most marked at R+1. Recovery was essentially complete at R+11.

CONCLUSIONS: The data argue for an environment-dependent memory store of frequently repeated sensory inputs that is under the guidance of a combined otolith, kinesthetic, and touch system. It registers the actual movement and allows for anticipation and compensation of each movement as it occurs. Being environmentally dependent, such a mechanism could account for the buildup of postural responses in zero-g that would be inappropriate upon return to one-g reference. A mechanism of this type could be applied to account for sensory physiological habituation in a variety of situations. In particular, such a mechanism could provide an adequate basis for change when the acquired response patterns are no longer congruent with the environment.

PUBLICATIONS: 279, 280

PRINCIPAL INVESTIGATOR(S): Jerry R. Hordinsky

EXPERIMENT TITLE/NUMBER: Skylab Crew Health - Crew Surgeons' Reports

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: The crew surgeon was responsible for the health of the Skylab crewmembers and their families, the development and use of the inflight medical support system, the preflight medical examination and arrangement of all crew medical-related activities, and the postflight coordination of medical activity.

PROTOCOL: The crew surgeon relied on the daily private medical conference with the crews over an air-to-ground loop from the NASA Mission Control Center to monitor crew health. For continuous clinical evaluation of the crew, the crew surgeon had access to medical parameters derived from the experiment data.

EQUIPMENT: None identified.

RESULTS: The crewmembers remained in excellent health except for a few minor clinical problems.

CONCLUSIONS: From a clinical point of view, all the physiological and psychological responses noted in the Skylab missions were either self-limiting or represented work-around problems requiring minimal counteraction. As such, these changes do not preclude extending man's duration in zero-gravity for longer periods of time.

PUBLICATIONS: 252, 281, 282

**PRINCIPAL INVESTIGATOR(S):** Kathy Jackson

**EXPERIMENT TITLE/NUMBER:** Motor Sensory Performance, ED41

**PROGRAM/MISSION:** Skylab 4

**CLASSIFICATION:** Human

**DISCIPLINE(S):** Behavioral science, Neurosensory

**OBJECTIVES:** To measure potential degradation of man's motor-sensory skills in the space environment.

**PROTOCOL:** Using a visual maze with 119 holes connected by straight lines, crewmen inserted a probe in each hole in sequence following the maze pattern. Visual perception and motor response were measured quantitatively by recording both total time required to transverse the entire maze and time required to move the probe from hole to hole.

**EQUIPMENT:** A standard eye-hand coordination test apparatus (developed by the Dept. of Industrial Engineering at the U. of Michigan); audio tape recorder, to record data as well as milli-second time marks; stylus, 5 in. long and 2 mm diameter.

**RESULTS:** Comparisons of preflight, inflight, and postflight data revealed no significant changes occurred in the eye-hand coordination of crewmembers.

**CONCLUSIONS:** Skylab astronauts were capable of normal motor-sensory activities during flight. None of the crewmen experienced any noticeable deterioration throughout the mission performing tasks that required them to handle experiments and controls.

**PUBLICATIONS:** 197, 377, 500

PRINCIPAL INVESTIGATOR(S): Philip C. Johnson, Theda B. Driscoll, and Adrian D. LeBlanc

EXPERIMENT TITLE/NUMBER: Blood Volume Changes, M113

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Hematology

OBJECTIVES: To determine the effects of weightlessness on the blood plasma volume and the red blood cell population, with particular attention paid to changes in the total mass of red cells, red cell destruction, red cell life span, and red cell production rate.

PROTOCOL: The red cell mass determination was obtained by averaging the red cell radioactivity of a 30- and 31- minute blood sample. Thirty days prior to launch, 50  $\mu$ Ci  $^{14}$ C-glycine were injected intravenously for a red cell life span study. At recovery, 2 Ci of  $^{59}$ Fe citrate were injected for calculation of iron turnover using the 30-, 31- minute samples and a sample drawn 2 to 3 hours later. Reticulocyte counts were obtained weekly preflight and postflight. Activity of  $^{51}$ Cr red cells was measured to estimate red cell chromium half-life. Plasma volume was measured by injecting 2  $\mu$ Ci  $^{125}$ I human serum albumin each time the red cell mass was determined.

EQUIPMENT: Inflight blood collection system.

RESULTS: The mean value of red cell mass of crewmembers showed a decrease of 5-12% through the first weeks inflight. The mean ratio of milliliters/kilogram body weight also decreased. Red cell mass regeneration did not occur until R+14. There was no difference in  $^{51}$ Cr T1/2 or the  $^{14}$ C glycine red cell mean life span pre- and postflight. There was no change in the rate of erythropoiesis. Reticulocyte counts were low at recovery.

CONCLUSIONS: A decrease in red cell mass is a constant occurrence in space flight, and the decrease does not seem to be caused by intravascular hemolysis. Splenic trapping of red cells is a plausible but untested explanation for the loss. After the initial loss, there is at least a 30-day delay before the red cell mass begins to reconstitute itself indicating bone marrow inhibition. Two unrelated biological changes may have been the cause of bone marrow inhibition. First, the plasma volume decreased causing tissues sensitive to peripheral hematocrit changes to not recognize the decrease in red cell mass. Later, serum phosphorus rose causing increased red cell release of oxygen. The oxygen-sensitive kidney would counter this by decreasing erythropoietin production. This combination of events probably explains the observed decrease in reticulocyte counts.

PUBLICATIONS: 291, 292, 293, 296

PRINCIPAL INVESTIGATOR(S): Robert L. Johnson, G. Wyckliffe Hoffler, Arnauld E. Nicogossian, Stuart A. Bergman, and Margaret M. Jackson

EXPERIMENT TITLE/NUMBER: Lower Body Negative Pressure, M092

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To determine the extent and time course of changes in orthostatic tolerance during the weightlessness of space flight and to determine whether inflight data from the experiment would be useful in predicting postflight status of orthostatic tolerance.

PROTOCOL: Basic measurements during all preflight, inflight, and postflight testing included blood pressure at 30-second intervals from an automatic system which detected and analyzed Korotkoff sounds, heart rate monitored continuously from one component of a Frank lead vectorcardiogram, and percentage change in calf volume monitored continuously from capacitive plethysmographic bands encircling the legs. Prior to LBNP tests, lower limb volume was estimated from girth measurements taken at 3 cm intervals between ankles and upper thighs.

EQUIPMENT: Lower Body Negative Pressure device.

RESULTS: At rest, inflight mean resting heart rates, systolic blood pressures, and pulse pressures were typically increased while diastolic and mean arterial pressures decreased compared to preflight values. Differences in inflight responses to LBNP stress from preflight responses included greater heart rate and leg volume increases in all crewmen and, in most, higher diastolic pressures and mean arterial pressures and lower systolic blood pressures and pulse pressures.

CONCLUSIONS: Inflight data confirmed that lower body negative pressure in weightlessness imposed a greater stress upon the cardiovascular system than in Earth's gravity. Changed relationships in the anatomical distribution of blood volume and extravascular fluids, altered patterns of blood flow, and reduced total circulating blood volume induced by the weightless environment are offered as partial explanations for the changes. The exaggerated inflight responses to lower body negative pressure generally appeared to decline after the first 30-50 days of flight. Inflight data served as a fairly accurate prediction of the initial postflight status of orthostatic tolerance.

PUBLICATIONS: 26, 27, 42, 211, 298, 299, 300, 301, 329, 576

PRINCIPAL INVESTIGATOR(S): Allan A. Katzberg

EXPERIMENT TITLE/NUMBER: The Effect of Space Flights on Living Human Cells

PROGRAM/MISSION: Discoverer XVII

CLASSIFICATION: Human

DISCIPLINE(S): Cell biology, Behavioral science

OBJECTIVES: To study traumatic effects of spaceflight on living human cells.

PROTOCOL: Rose chambers were seeded with about 100,000 cells of both conjunctival and synovial cells. The medium consisted of 2cc salt solution and 10% horse serum. Ground and laboratory controls were set up. Twelve days after preparation, the cultures were flown, and were returned to the lab 16 days after preparation for analysis.

EQUIPMENT: Rose chambers, 10% horse serum, refrigeration units, salt solution, chemical dosimeters, alanine, albumin, silver-activated phosphate glass rods, neutron sensitive film, Ansco 552 film, nuclear track.

RESULTS: Preliminary observation indicated that the cells were in an advanced state of degeneration. On the 12th day, there were signs of survival, and 8 days later, there was new growth in the flight cultures. The mortality rate was the same in control and flight samples.

CONCLUSIONS: The degeneration of the cells was probably due to exhaustion of the nutrient media. Since the mortality rate was the same in flight and the ground controls, radiation alone cannot be held solely responsible for the cellular death and damage that occurred.

PUBLICATIONS: 305, 306, 307, 308

PRINCIPAL INVESTIGATOR(S): Allan A. Katzberg

EXPERIMENT TITLE/NUMBER: The Effects of Space Flights on Living Human Cells

PROGRAM/MISSION: Discoverer XVIII

CLASSIFICATION: Human

DISCIPLINE(S): Cell biology, Behavioral science

OBJECTIVES: To study traumatic effects of spaceflight on living human cells.

PROTOCOL: Seven human cell lines were used. The types of ectodermal cells flown were: amnion and conjunctival, the mesoderm cells were: sternal marrow, synovial, monocytic leukemia and hela, and the endodermal cells were from the embryonic lung. A population of 50 000 cells of each type was suspended in 3cc medium and sealed in glass ampules which also contained a small glass coverslip.

EQUIPMENT: Glass ampules, salt solution, 10% horse serum, refrigeration units, neutron film pack, chemical dosimeters, gold foil, glass needle sets, 552 film strips, polyethylene foam (for packing), alanine packets, 1 step plate and film (in all three planes), nuclear track plates.

RESULTS: The cultures were in good condition when returned on the 12th day following preparation, with a high level of viability. Postflight, the cells showed no significant biochemical, cytological, or genetic changes.

CONCLUSIONS: None, due to less than ideal experimental conditions.

PUBLICATIONS: 305, 306, 307, 308

PRINCIPAL INVESTIGATOR(S): Peter Kellaway, and Robert L. Maulsby

EXPERIMENT TITLE/NUMBER: Analysis of Inflight Sleep, M006

PROGRAM/MISSION: Gemini 7

CLASSIFICATION: Human

DISCIPLINE(S): Neurosensory, Behavioral science

OBJECTIVES: To obtain an objective evaluation of the pilot's sleep pattern in order to discover any deviation from patterns recorded on earth, to assist in revealing factors which may interfere with sleep in orbit, and to determine the effects of weightlessness on the electrical activity of the brain.

PROTOCOL: Two channels of EEG data were recorded on a tape recorder from electrodes attached to the scalp. Transistorized signal conditioners were worn in pockets of the astronaut's underwear.

EQUIPMENT: EEG electrodes, recording system consisting of two miniature transistorized amplifiers, and a small magnetic tape recorder.

RESULTS: Normal sleep patterns changed, mainly as a result of staggered sleep periods, alterations from preflight diurnal cycles, and cyclical cabin noise. The first sleep period was inadequate in terms of length and depth of sleep. The second was adequate but may have been so because of fatigue from sleep loss in the first period.

CONCLUSIONS: This experiment demonstrated the feasibility of monitoring an EEG during spaceflight. It was of good quality and was recorded for a relatively long period of time. No abnormalities were revealed and there were no obvious changes attributable to weightlessness. Orbital flight appears to have no deleterious effect on the activity of the brain.

PUBLICATIONS: 309, 310, 311, 312

PRINCIPAL INVESTIGATOR(S): Stephen L. Kinzey, and Philip C. Johnson

EXPERIMENT TITLE/NUMBER: Hematological and Immunological Studies

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Hematology, Immunology

OBJECTIVES: To provide hematologic and immunologic data to the Apollo-Soyuz Test Project (ASTP) crew surgeon that was necessary for the objective assessment of the crew's health status before launch and during the period immediately after flight and to evaluate the influence of space flight on the circulating blood volume.

PROTOCOL: Blood samples were collected by venipuncture preflight on days F-30, F-15, and F-5 and for 4 weeks postflight. Radioisotope studies were conducted on days F-15, R+0, and R+29.

EQUIPMENT: Blood collection device.

RESULTS: Red cell mass was reduced 9% at R+0 and remained below normal through R+28. HCT and Hb were slightly reduced at R+0 and were reduced 10-15% at R+8. Slight postflight reduction in RBC count was found. There was a postflight elevation in WBC count (Neutrophils). A significant shift occurred in the red cell shape classification after flight. An elevation in methemoglobin occurred at R+0. Individuals showed varied immunologic responses. No significant plasma protein abnormalities were found preflight or postflight. Constituents studied were: total protein, albumin, globulins  $\alpha$ 2-macro,  $\alpha$ 1,  $\alpha$ 2,  $\beta$ ,  $\gamma$ , C, M, D, A, haptoglobin, 1-glycoprotein, 1-antitrypsin, C3, ceruloplasmin, LDH 1-5, lipoproteins  $\alpha$ ,  $\beta$ , pre- $\beta$ .

CONCLUSIONS: Most of the changes observed in the hematologic and immunologic functions of the ASTP crewmen as a result of their exposure to space flight were subtle and/or transient. The changes in RBC, Hb, and HCT were the result of shifts in plasma volume during the flight and immediately after flight. The exposure of the crew to a toxic gas during reentry complicated the interpretation of those changes observed. This exposure may have particular significance with respect to the altered red cell shape profile after flight and its slow rate of recovery.

PUBLICATIONS: 314

PRINCIPAL INVESTIGATOR(S): Stephen L. Kimzey, Craig L. Fischer, Philip C. Johnson, Stephan E. Ritzmann, and Charles E. Mengel

EXPERIMENT TITLE/NUMBER: Hematology and Immunology Studies

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human

DISCIPLINE(S): Hematology, Immunology

OBJECTIVES: To acquire specific laboratory data relative to the assessment of the health status of the astronauts prior to their commitment to space flight, to detect and identify any alterations in the normal functions of the immunohematologic systems which could be attributed to space flight exposure, and to evaluate the significance of these changes relative to man's continuing participation in space flight missions.

PROTOCOL: Routine blood procedures were red blood cell count, reticulocyte count, hemoglobin, hematocrit, red cell indices, white blood cell count, white cell differential count, platelet count, and total eosinophil count. There were some special hematology procedures, such as blood volume, RBC metabolism, and cellular analysis. Samples were obtained by venipuncture on F-30, R+3 hr., and for 2 weeks postflight. Three ground controls were used.

For the cytogenetic studies, peripheral blood samples were collected and heparinized. After centrifugation, the buffy coat was preserved for chromosome cultures and the serum and erythrocytes were used for other laboratory experiments. The cultures were harvested after 66 hours incubation at 37°C. Slides were prepared and the cells stained. Preflight blood samples were collected from 30 days to one day prior to lift-off. Postflight samples were drawn on the day of recovery or within four days. 200 to 1000 metaphase cells were scored for each individual.

For the immunology studies, the serum proteins were assayed serially before flight, immediately after recovery, and for varying periods of time (up to two weeks) after flight. Serum protein electrophoretic patterns were obtained by cellulose acetate electrophoresis, from which albumin,  $\alpha_2$ -globulin and  $\gamma$ -globulin fractions were computed. Individual serum proteins were quantitated by radial immunodiffusion (RID), using specific antisera. Proteins assayed by RID include immunoglobulins G, A, and M (I<sub>G</sub>, I<sub>A</sub>, I<sub>M</sub>), the third component of complement (C<sub>3</sub>), the carrier proteins transferrin<sup>g</sup>, haptoglobin and ceruloplasmin, the antiproteases,  $\alpha_1$ -antitrypsin, and  $\alpha_2$ -macroglobulin, and  $\alpha_1$ -acid glycoprotein.

Lymphocytes were separated from heparinized venous blood by a nylon reticulum column, cultured, and pulsed with  $^3\text{H}$ -uridine or  $^3\text{H}$ -thymidine. This was measured by liquid scintillation spectrometry for RNA and DNA synthesis. Red cell mass was measured using  $^{51}\text{Cr}$ .

EQUIPMENT: Blood collection device and assay equipment.

RESULTS: Postflight reduction in RBC and reticulocyte counts were found. WBC and platelet counts were slightly elevated in the initial postflight (R+0) test.

Human lymphocyte response (uptake of  $^3\text{H}$  uridine or  $^3\text{H}$  thymidine) to phytohemagglutinin was within normal limits. A 2-10% decrease in red cell mass was noted. The HCT was unchanged initially but reduced at R+7. Hb was elevated slightly at R+0, and reduced at R+7. MCHC was elevated through the first week, postflight. RBC T1/2 remained unchanged.

A significant increase of echinocyte population (R-2h) was noted with immediate postflight reversal (R+0). Other morphological types (discocyte, leptocyte, codocyte, stomatocyte, knizocyte) remained unchanged. Inflight distribution of types varied, but not significantly. The number of echinocytes was possibly related to the length of flight.

The immunology studies showed that the concentration of serum proteins was increased after flight. There was no increase in RNA or DNA synthesis. No significant abnormalities were demonstrated preflight or postflight.

The chromosome analysis suggested postflight aberrations were approximately double preflight values. There was a rather constant postflight aberration yield which seemed to be dependent on the duration of the flight, and baseline or preflight values in experienced astronauts appeared to be higher than in the other crewmen.

CONCLUSIONS: Although there were subtle alterations for some aspects of erythrocyte function, plasma protein profiles, lymphocyte response patterns, and chromosome aberrations, none of these changes compromise man's performance capacity while in space or should limit his stay in space. While questions remain unanswered, especially with respect to longer duration missions, no drastic alterations were observed during the Apollo program for the hematological and immunological systems which would cause serious concern for the health and safety of the crewmen on longer space journeys.

PUBLICATIONS: 193, 194, 195, 297, 315

PRINCIPAL INVESTIGATOR(S): Stephen L. Kimzey

EXPERIMENT TITLE/NUMBER: Hematology and Immunology Studies, M115

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Hematology, Immunology

OBJECTIVES: To examine critical physiological blood parameters relative to a stable state of equilibrium between certain blood components and evaluate the effects of weightlessness upon these parameters, and to provide other data on blood and blood circulation which will assist in the interpretation of hematology and immunity, nutrition and musculoskeletal function experiments.

PROTOCOL: Blood samples were collected by venipuncture from the crew and ground-control subjects periodically during the preflight, inflight, and postflight phases of each mission. Depending on the assay to be conducted, different anticoagulents were used. All samples were processed or stabilized within minutes of collection. Inflight samples were collected in Na<sub>2</sub> EDTA and immediately separated by centrifugation into plasma and cellular phases. The inflight samples were frozen at -20 degrees C and stored onboard until recovery, whereby the specimens were then transferred to the lab for analysis.

EQUIPMENT: Blood collection device.

RESULTS: No significant changes in the plasma protein profiles were found in the immunology studies. An insignificant reduced human lymphocyte response (uptake of <sup>3</sup>H uridine or <sup>3</sup>H thymidine) to phytohemagglutinin on R+0 was noted. It was within normal range on days R+3-7. Suppression of T-cell numbers (by E-rosette), an elevation of B-cell numbers, and normal total lymphocytes were found.

RBC count was unchanged at R+0, but slightly reduced by R+7. WBC was elevated at R+0 and reticulocyte count was decreased at R+0, but elevated at R+7.

A loss of red cell mass and plasma volume and reduction in hemoglobin concentration were found. There was a shift in the specific gravity in the red cell population. K content of the red cells remained unchanged. There was a significant variation in the distribution of cell types inflight. An increase in echinocytes was found inflight with immediate postflight reversal. Other types were unchanged.

CONCLUSIONS: The increased amount of physical exercise in the later Skylab missions may have resulted in a prevention of alterations in plasma protein profiles. The exact cause and impact of the reduced lymphocyte responsiveness

was not determined. The change in specific gravity may represent an alteration of red cell lipid content, cell water content, cell electrolyte concentration, or a combination of the three. Most changes in red cell shape induced by intrinsic factors and those related to aged red cells are not readily reversible. This observation would support the concept of a change in one of the plasma constituents and its uptake by the cell membrane as being the primary cause of the shape changes. The significance of the observed red cell shape transformation is not readily apparent.

PUBLICATIONS: 313, 316, 317, 318

PRINCIPAL INVESTIGATOR(S): Joseph F. Kubis, Edward J. McLaughlin, Janice M. Jackson, Rudolph Rusnak, Gary H. McBride, and Susan V. Saxon

EXPERIMENT TITLE/NUMBER: Task and Work Performance on Skylab Missions 2, 3, and 4, M151

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Neurosensory, Behavioral science

OBJECTIVES: To observe astronauts in motion, compare their mobility and dexterity in various activities under weightlessness with similar activities under Earth conditions, and to evaluate their zero-gravity behavior for designs and work programs of future spacecraft.

PROTOCOL: The following tasks were selected for observation: locomotion of crewmen as they moved in zero-g environment with and without loads, fine and gross motor activities of crewmen in performing operations with and without the use of restraints, tasks which required visual, tactile, or auditory feedback, or combinations of feedbacks, intravehicular and extravehicular activities, and repeated activities performed early, midway, and late in the missions showing adaptation to the zero-g environment. Films were made with verbal information by the astronauts.

EQUIPMENT: 16mm movie camera, portable high intensity photographic lamp, tape recorder.

RESULTS: There was uniformity of crew performance over the missions. Initial change from preflight to inflight environment was accompanied by an increase in performance time for the majority of work task activities studies. By the end of the second inflight trial, more than half of the activities were performed as efficiently as on the last preflight trial. Performance proficiency increased during each Skylab mission with crewmen adjusting rapidly to the weightless environment and becoming proficient in developing techniques to optimize task performance.

CONCLUSIONS: There was no evidence of performance deterioration that could be attributed to the effects of long duration exposure to the Skylab environment. Performance adaptation was very rapid. By the end of the second performance trial, about 50% of all task elements were completed within the time observed for the last preflight trial.

PUBLICATIONS: 320, 321, 322

PRINCIPAL INVESTIGATOR(S): Earl V. LaFevers, Arnauld E. Nicogossian, William N. Hursta, and Joseph T. Baker

EXPERIMENT TITLE/NUMBER: Electromyographic Analysis of Skeletal Muscle

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal, Neurosensory

OBJECTIVES: To investigate changes in skeletal muscle electrical activity that occur after exposure to short-term weightlessness.

PROTOCOL: Data were obtained on days F-45, F-30, and F-15. Surface electrodes were placed on the lower leg muscles (gastrocnemius and soleus) and on the arm muscles (biceps brachii and brachioradialis). Seated in the muscle stress apparatus, the crewman was instructed to exert a series of graded efforts.

EQUIPMENT: A skeletal muscle stress apparatus, electromyogram.

RESULTS: Skeletal muscle disuse attributable to 9 days of space flight weightlessness resulted in increased excitability of the instrumented muscles.

The ratios of integrated electromyogram (IEMG) to force for both the gastrocnemius and brachioradialis muscles showed a decreased level of electrical efficiency as a result of the 9 days in weightlessness. The data for the biceps and brachioradialis muscles show a tendency for increased electrical efficiency.

Significant shifting of the power spectra into lower frequencies was considered evidence of muscle fatigability. In the leg muscle, there was a significant difference between preflight and postflight spectral power levels. The postflight data showed a significantly greater progressive power shift into the lower frequencies as a result of the 1-minute isometric stress. The arm muscles did not exhibit significant differences between conditions.

CONCLUSIONS: Both upper and lower extremity muscles showed changes in excitability which suggest that skeletal muscles are susceptible to functional changes associated with the reduced muscle activity in weightlessness. Since all changes showed increased sensitivity, the probable site for this effect is the muscle fibers, for the following reason: Previous clinical studies have shown that random loss or reduced activity in muscle fibers, as in myopathy, result in higher firing frequencies of the muscle, whereas dysfunctions of neural loci result in lower firing frequencies.

Short-term exposure to weightlessness heightens fatigability in skeletal muscle. Greater amounts of spectral power were observed in the lower

frequencies after weightlessness than before in response to the fatigue-inducing stress. The disuse associated with whole body weightlessness temporarily facilitated certain muscle conditions.

PUBLICATIONS: 327, 328

PRINCIPAL INVESTIGATOR(S): Carolyn S. Leach, and Paul C. Rambaut

EXPERIMENT TITLE/NUMBER: Biochemical Responses of the Skylab Crewmen, M073

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Endocrinology, Environmental health

OBJECTIVES: To assess the effect of space flight on endocrine and metabolic functions including fluid and electrolyte control mechanisms.

PROTOCOL: Metabolic monitoring began on day F-21 and continued through day R+17. Blood and urine samples were collected preflight, inflight, and postflight. For the blood samples, Na<sub>2</sub> EDTA was used as an anticoagulant. Radioassay, fluorometric and gas chromatographic techniques were used for most hormonal analyses. Radionuclide body compartment studies were conducted preflight and postflight. These included dilution studies of total body water (tritium), extracellular fluid (<sup>35</sup>Sulphate), plasma volume (<sup>125</sup>I-protein) and exchangeable potassium (<sup>42</sup>K and <sup>43</sup>K).

EQUIPMENT: Blood collection device, urine collection device.

RESULTS: In the blood samples, elevations were found in Ca and PO<sub>4</sub> inflight and remained high for several days postflight. Cortisol and angiotensin I were generally elevated. K and creatinine increased inflight and remained high immediately after recovery. Plasma aldosterone, total protein, carbon dioxide, thyroid stimulating hormone, and thyroxine were increased postflight. Reduction was noted in Na, Cl, osmolality and ACTH inflight and postflight. There were postflight decreases in cholesterol, uric acid, magnesium, lactic dehydrogenase, and total bilirubin. BUN and albumin were unchanged at R+0, but decreased R+3 and R+14. All electrolytes in the 24-hour urine samples were increased inflight along with aldosterone, cortisol, and total 17-ketosteroids. Postflight increases were seen in epinephrine, norepinephrine, aldosterone, and cortisol. There were trends toward inflight decreases in ADH, epinephrine, norepinephrine, and uric acid. Decreases were noted postflight in Na, K, Cl, osmolality, PO<sub>4</sub>, magnesium, uric acid, ADH, and total 17-hydroxycorticosteroids.

CONCLUSIONS: Significant biochemical changes were observed, varying in magnitude and direction, but all disappeared shortly after return to Earth. These changes are an indication of successful adaptation of the body to the combined stresses of weightlessness. The transient nature of some of these changes, particularly in fluid and electrolyte metabolism, tend to support the conclusion that a new and stable condition of homeostasis had been achieved.

PUBLICATIONS: 293, 334, 335, 336, 337, 338, 340, 345, 346, 347, 533

PRINCIPAL INVESTIGATOR(S): Carolyn S. Leach

EXPERIMENT TITLE/NUMBER: Biochemistry and Endocrinology Results

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Endocrinology, Environmental health

OBJECTIVES: To provide data which would permit an objective assessment of the individual crewman's health. The data collected during preflight provided baseline information for detecting and identifying postflight physiological changes which may have resulted from exposure to the space flight environment.

PROTOCOL: Analyses were performed on venous blood on days F-30, F-15, and F-5. Postflight blood was drawn as soon as possible after recovery and R+28. All preflight blood samples were obtained after fasting. On the same day that blood was drawn, 24-hour urine samples were collected from each crewman.

EQUIPMENT: Blood collection device, urine collection device.

RESULTS: BUN, creatinine, and SGPT were elevated postflight. A decrease was seen in CPK, uric acid, cholesterol, and triglycerides. A postflight decrease in urine volume, Na, K, Cl, and  $PO_4$ , and an increase in Ca excretion were found. Cortisol, aldosterone, and angiotensin were elevated at R+0. ADH and norepinephrine were decreased at R+0. All were decreased R+28.

CONCLUSIONS: The test results of U. S. crewmen on the 9-day ASTP flight were similar to the findings on recovery of previous space flight crews from missions of comparable duration.

PUBLICATIONS: 334, 339

PRINCIPAL INVESTIGATOR(S): Carolyn S. Leach, W. Carter Alexander, and Philip C. Johnson

EXPERIMENT TITLE/NUMBER: Endocrine, Electrolyte, and Fluid Volume Changes Associated with Apollo Missions

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human

DISCIPLINE(S): Endocrinology, Environmental health

OBJECTIVES: To evaluate the biochemical changes in Apollo crewmembers. The areas studied were balance of fluids and electrolytes, regulation of calcium metabolism, adaptation to the environment, and regulation of metabolic processes.

PROTOCOL: The same protocol was used for all the Apollo missions except 11, 12, and 14, which were in the lunar quarantine program. 45 ml of venous blood was drawn 3 times before flight. 24 hour urine samples were collected pre- and postflight at the same time. There was a ground control to determine transport effects on the samples. Blood was analyzed for osmolality, Na, K, Cl, ACTH, angiotensin I, cortisol, HGH, insulin, parathormone, thyroxine, and triiodothyronine. Urine was analyzed for electrolytes, osmolality, volume, aldosterone, cortisol, ADH, ketosteroids, and amino acids. Radionuclide studies were used.

EQUIPMENT: Blood and urine collection devices, bioassay equipment.

RESULTS: Total body water, and extra- and intracellular fluids decreased 2%. Plasma volume was reduced 4%. There was a postflight decrease in urine volume, and increase in osmolality. Na, K, Cl, and Mg decreased. At R+0, cortisol, aldosterone, HGH, ADH, pregnanediol were elevated. Epinephrine, 17-hydroxycorticosteroids, androsterone, etiocholanolone decreased. At R+0, the amino acids taurine, sarcosine, and B-alanine were elevated, whereas, glycine, alanine, and tyrosine were reduced.

CONCLUSIONS: The following hypothesis is presented to explain the mechanisms underlying the observed electrolyte and fluid compartment changes: In a weightless environment, there is a tendency for plasma volume to be distributed more evenly within the vascular system and away from the gravity-dependent extremities. This shift is interpreted by receptors, probably in the right atrium, to be an increase in vascular volume. The increase in vascular volume is counteracted by an increased water loss, followed by a compensatory, adrenal-pituitary-mediated retention of water and sodium and by a continued loss of potassium. Other hormone changes observed are tentatively ascribed to the stresses associated with the condition of the Apollo space flights, to the well known consequences of hypokinesia, and to the metabolic effects of hypocaloric nutritional intake.

PUBLICATIONS: 294, 295, 333, 337, 342, 343, 344, 348, 438, 474, 561

PRINCIPAL INVESTIGATOR(S): Lillian H. Lockhart

EXPERIMENT TITLE/NUMBER: Cytogenetic Studies of Blood, M111

PROGRAM/MISSION: Skylab 2, 3,

CLASSIFICATION: Human

DISCIPLINE(S): Genetics, Hematology

OBJECTIVES: To analyze the chromosome patterns of astronauts preflight and postflight giving special attention to findings suggestive of exposure to ionizing irradiation.

PROTOCOL: Blood lymphocyte studies were performed 5 times preflight and 6 times postflight. A total of 77 specimens were cultured and processed. The cultures were incubated for 60 to 70 hours and processed by treatment with Colcemid for 2 hours. The cell suspension was then treated with a hypotonic solution and fixed with methanol and acetic acid. Slides were prepared by flame drying. After Wright's staining, approximately 125 cells were examined from each culture for minor structural defects and rearrangements. Each cell with numerical or structural defects was photographed and karyotyped to determine the chromosomes involved in the aberrations.

EQUIPMENT: Blood collection device.

RESULTS: Cytogenetic analysis of lymphocytes for fragments, deletions, dicentrics, rings, exchange figures, translocations, and inversions showed minor structural defects within normal range but major rearrangements were increased. It seems unrelated to flight as it also occurred in the ground control. The etiology is unknown.

CONCLUSIONS: It is impossible to speculate as to the effects of high altitude flying and weightlessness on the chromosome structure of man. It would appear, however, that the flights were not a significant factor in contributing to the increase in minor chromosomal aberrations or the appearance of chromosomal rearrangements.

PUBLICATIONS: 352, 353

PRINCIPAL INVESTIGATOR(S): Pauline B. Mack, George P. Vose Fred B. Vogt, and Paul A. LaCharce

EXPERIMENT TITLE/NUMBER: Bone Demineralization, 4006

PROGRAM/MISSION: Gemini 4, 5, 7

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To find the effect upon the human skeletal system of prolonged weightlessness and immobilization associated with confinement for a period of days in the Gemini spacecraft.

PROTOCOL: The measurements of bone demineralization were made using radiographic bone densitometry. Radiographs were made preflight and postflight of the left foot in lateral projection and the left hand in posterior-anterior projection. They were taken at F-10 days and F-3 days, at R+0, R+24 hours, R+11 days, and R+47 days. Sections of the os calcis, talus and hand phalanges were evaluated for changes in skeletal mineralization.

EQUIPMENT: Analog computer and X-ray unit.

RESULTS: Postflight X-ray densitometry showed decreases in bone mass. However, rapid gains were found during the first 12 hours after recovery. The losses in the crewmen of Gemini 7 tended to be lower in all anatomical sections than those in the Gemini 4 and 5 crewmen who consumed about 1/3 as much calcium inflight.

CONCLUSIONS: The level of food intake undoubtedly has been one of the major parameters accountable for the differences in levels on mineral loss by the astronauts. The Gemini 7 astronauts engaged in isotonic and isometric exercises and slept for longer periods than Gemini 4 and 5 astronauts which may also explain the differences. The findings of this study show that time is not the chief factor responsible for skeletal loss during space flight. Skeletal losses were replaced within short period after recovery.

PUBLICATIONS: 323, 324, 325, 326, 367, 370, 371, 372, 541

PRINCIPAL INVESTIGATOR(S): Russell R. Martin, Glenn A. War. Margaret J. Putman, Diane H. Kentor, and Carolinda L. Holleman

EXPERIMENT TITLE/NUMBER: Polymorphonuclear Leukocyte Response

PROGRAM/MISSION: Apollo-Soyuz Test Project, MA032

CLASSIFICATION: Human

DISCIPLINE(S): Hematology, Cell biology, Behavioral science

OBJECTIVES: To identify any measurable polymorphonuclear leukocyte (PMN) alterations that might be significant in planning future, longer duration space missions.

PROTOCOL: Blood samples were obtained periodically from the crewmen between F-30 to R+30. The back-up crew were studied during the preflight period and served as a normal control population. Tests performed included total leukocyte count, differential count, measurement of leukocyte adhesion, evaluation of leukocyte migration and chemotaxis, assessment of phagocytic ability, and testing for cytoplasmic granules that stained for leukocyte acid and alkaline phosphatase.

EQUIPMENT:

RESULTS: *In vitro* responses showed no abnormality R+0 to R+30. Leukocyte acid and alkaline phosphatase histochemistry was unchanged.

CONCLUSIONS: The absence of any substantial change in the function studies performed suggests that a 9-day space mission does not impair PMN function to any significant extent. The crewmembers returning from space flight have not exhibited increased clinical susceptibility to infection.

PUBLICATIONS: 378. 379

PRINCIPAL INVESTIGATOR(S): Todd Meister

EXPERIMENT TITLE/NUMBER: In vitro Immunology, ED32

PROGRAM/MISSION: Skylab 3

CLASSIFICATION: Human

DISCIPLINE(S): Immunology

OBJECTIVES: To observe In vitro the effects of zero gravity on a precipitin-type antigen-antibody reaction.

PROTOCOL: Measured amounts of human antigen were used to inoculate 3 plates containing agar and antibodies, providing each plate with a different combination of antigen/antibody. The plates were stored at Skylab ambient temperature (approx. 77° F) for 2 days. Starting 24 hours after inoculation, photographs were taken every 5 hours. Growth rates of the precipitin rings were compared with those of the control experiment on earth.

EQUIPMENT: 3 radial immunodiffusion plates, 1 thermos bottle-type cooler, 3 Hamilton syringes.

RESULTS: Small rings which grew during the 48-hour period were visible in some of the chambers. Much of the agar became dried and cracked after 23 hours of incubation. Nine of 18 chambers had formed precipitin rings at approximately the same growth rates and with similar intensities as earth controls.

CONCLUSIONS: Those reactions which occurred provided evidence that the immune reaction system functioned normally in the space environment.

PUBLICATIONS: 197, 377, 393, 500

PRINCIPAL INVESTIGATOR(S): Charles E. Mengel

EXPERIMENT TITLE/NUMBER: Red Cell Metabolism Studies on Skylab

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Hematology

OBJECTIVES: To study the effects of gravity on the membrane and the metabolism of the human red blood cell, and to determine whether any metabolic changes or membrane modifications occurred as a result of exposure to the space flight environment.

PROTOCOL: Blood samples of each crewman were taken on days F-21, F-7, and F-1, 4 times during the first and 8 times during the second and third missions, and on days R+0, R+1, and R+14. Blood was analyzed for methemoglobin, glucose-6-phosphate dehydrogenase, phosphoglyceric kinase, lipid peroxides, reduced glutathione, adenosine triphosphate, glyceraldehyde phosphate dehydrogenase, pyruvate kinase, acetylcholinesterase, phosphofructokinase, 2, 3-diphosphoglyceric acid, and hexokinase. Inflight samples were frozen and returned to Earth for postflight analysis.

EQUIPMENT: Inflight Blood Collection System.

RESULTS: Inflight increases of hexokinase, pyruvate kinase, and glyceraldehyde phosphate dehydrogenase were found. Changes of adenosine triphosphate and 2, 3-diphosphoglyceric acid were not significant. There was a significant postflight decrease of phosphofructokinase. Significant decreases inflight of phosphoglyceric kinase and acetylcholinesterase and increases of pyruvate kinase were found.

CONCLUSIONS: It is possible to conclude that there are no evidences of lipid peroxidation (that biochemical effect known to be associated with irreversible red cell damage). The changes observed in glycolytic intermediates and enzymes cannot be directly implicated as indicating evidence of red cell damage.

PUBLICATIONS: 394, 395

PRINCIPAL INVESTIGATOR(S): Edward L. Michel, John A. Rummel, Charles F. Sawin, Melvin C. Buderer, and John D. Lem

EXPERIMENT TITLE/NUMBER: Metabolic Activity, M171

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Respiratory. Behavioral science

OBJECTIVES: To determine whether man's metabolic effectiveness while performing mechanical work is progressively altered by exposure to the space environment and to evaluate the M171 bicycle ergometer as an inflight crew personal exerciser.

PROTOCOL: Exercise protocol on the bicycle ergometer was 5 min. rest, 5 min. at 25% max.  $\dot{V}O_2$ , 5 min. at 50% max.  $\dot{V}O_2$ , 5 min. at 75% max.  $\dot{V}O_2$ , and 5 min. recovery. Eight baseline tests were conducted by the crew. Inflight testing occurred about every 6 days. There were eight modified tests postflight. For Skylab 4, the preflight and postflight tests included both upright and supine ergometry. Data was collected on ergometer work rate, ergometer RPM, oxygen uptake, carbon dioxide output, minute volume, vital capacity, respiratory quotient, heart rate, blood pressure, vectorcardiogram, body weight, body temperature, and Skylab environmental parameters.

EQUIPMENT: Ergometer, blood pressure measuring system, vectorcardiograph/heart rate system, metabolic analyzer consisting of a spirometer, a mass spectrometer, and an analog computer.

RESULTS: Inflight exercise was characterized by significantly reduced oxygen consumption and diastolic blood pressure. Other responses were within normal preflight limits.

Postflight (R+0) tests showed significantly decreased cardiac output (-30%) and increased total systemic peripheral vascular resistance. Heart rate was elevated while mean stroke volume decreased 45%. Mean arterial pressure and oxygen consumption were unchanged. Return to normal preflight values occurred by R+26-31.

Flight duration did not significantly influence the magnitude of changes or time for return to normal. Skylab 2 reached preflight exercise response by R+21, whereas Skylab 3 and 4 reached preflight exercise response by R+4-5.

CONCLUSIONS: It appears that the observed responses were a result of a decreased venous return caused by an altered fluid balance/blood volume state coupled with possible reductions in vascular tone of the venous system. Exercise capacity inflight was not compromised.

PUBLICATIONS: 106, 396, 397, 398, 455, 463

PRINCIPAL INVESTIGATOR(S): Philip O'B. Montgomery, J. E. Cook, R. C. Reynolds, J. S. Paul, L. Hayflick, D. Stock, W. W. Schulz, Stephen L. Kimzey, Robert G. Thirolf, Thomas D. Rogers, and J. Murrell

EXPERIMENT TITLE/NUMBER: The Response of Single Human Cells to Zero Gravity, S015

PROGRAM/MISSION: Skylab 3

CLASSIFICATION: Human

DISCIPLINE(S): Cell biology

OBJECTIVES: To detect the effects of zero-gravity on cell growth rates and cell structure and function.

PROTOCOL: A strain of diploid human embryonic cells (WI-38) was used for this study. Cell growth rates were observed by light microscopy, transmission and scanning electron microscopy, and histochemistry. Studies of the cell function and cell cycle were performed by time lapse motion picture photography and microspectrophotometry. Study of returned living cells included karyotyping, G- and C-banding, and analyses of the culture media. Ground control units were used for comparison of results.

EQUIPMENT: Woodlawn Wanderer 9 with a camera-microscope system, specimen chambers, and a growth curve module.

RESULTS: Human embryonic lung cells showed normal growth, cell cycle times, G- and C- chromosome banding and rearrangement, DNA, and mitotic index. Phase, electron and scanning microscopy showed no differences.

CONCLUSIONS: Within the limits of the experimental design, it was found that a zero-gravity environment produced no detectable effects on human embryonic lung cells in tissue culture.

PUBLICATIONS: 403, 404, 405, 406

PRINCIPAL INVESTIGATOR(S): Arnauld E. Nicogossian, Charles K. LaPinta, Eduard C. Burchard, G. Wyckliffe Hoffler, and Peter J. Bartelloni

EXPERIMENT TITLE/NUMBER: Crew Health

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To insure the health and safety of crewmembers.

PROTOCOL: Physical examination, inflight biomedical instrumentation.

EQUIPMENT: Bioinstrumentation electrodes.

RESULTS: All three crewmembers experienced the now classical fullness-of-the-head sensation immediately after Earth-orbital insertion. This symptom was mild and did not interfere with the crew's performance.

The U. S. crew was exposed to toxic gases, mostly nitrogen tetroxide ( $N_2O_4$ ), from inadvertent reaction control system (RCS) firings during the descent phase, 30 seconds after drogue deployment. The  $N_2O_4$  entered the CM through the cabin pressure relief valve, which was opened during the landing sequence.

The chief complaints consisted of burning of the eyes with profuse tearing, burning sensation and itching of the exposed skin surfaces which subsided shortly after they left the spacecraft, tightness of the chest, retrosternal burning sensation, and inability to inhale deeply which led to a nonproductive and nonspasmodic cough. The review of systems was noncontributory. The three astronauts were in no acute distress and all were oriented to time, person, and place.

CONCLUSIONS: Follow-up detailed medical evaluations were performed 4 weeks after the initial exposure to  $N_2O_4$  vapors. It was established that there were no obvious residual after effects from the exposure to toxic fumes.

PUBLICATIONS: 407

PRINCIPAL INVESTIGATOR(S): Arnauld E. Nicogossian, G. Wyckliffe Hoffler,  
Robert L. Johnson, and Richard J. Gowen

EXPERIMENT TITLE/NUMBER: Determination of Cardiac Size From Chest  
Roentgenograms Following Skylab Missions

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To measure and evaluate changes in cardiac size.

PROTOCOL: Standard posteroanterior chest films in systole and diastole were obtained preflight and within a few hours after recovery on each of the Skylab astronauts. Postflight chest X-rays were visually compared to the preflight roentgenograms for possible changes in pulmonary vasculature, lung parenchyma, and bony or soft tissue structures. From these roentgenograms the following measurements were obtained: cardiac and thoracic transverse diameters, cardiothoracic transverse diameter ratio, cardiac area from the product of both diagonal diameters, cardiac silhouette area by planimetry, thoracic cage area and cardiothoracic area ratio

EQUIPMENT: X-ray equipment.

RESULTS: There were significantly decreased cardiac silhouette areas, and cardiothoracic transverse diameter ratios postflight. No correlation was found between length of mission and change in size. Normalization occurred by R+5. Postflight echocardiographic analysis showed ventricular dimensions unchanged on Skylab 4.

CONCLUSIONS: The observed postflight decrease in frontal plane cardiac silhouette size could be attributed to a decrease in myocardial tissue mass and/or intrachamber blood content, anatomical reorientation, or a combination of these factors. Caudal displacement of blood and other fluids together with an absolute decrease in the circulating blood volume could account for the observed decreases in the cardiac silhouette size. A small diastolic size might more clearly delineate a deficit in blood return and chamber filling rather than loss of myocardial mass.

PUBLICATIONS: 408, 409

PRINCIPAL INVESTIGATOR(S): Arnauld E. Nicogossian, Charles F. Sawin, and Peter J. Bartelloni

EXPERIMENT TITLE/NUMBER: Results of Pulmonary Function Tests

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Respiratory

OBJECTIVES: To measure pulmonary function in weightlessness.

PROTOCOL: Preflight pulmonary function tests were performed in conjunction with other medical evaluations on days F-45, F-30, and F-15. Because of hardware malfunction on day F-45, data were not amenable to analysis and only two sets of data were used for baseline purposes. Following exposure to nitrogen tetroxide and 10 minutes prebreathing of 100% oxygen, pulmonary function screening tests were obtained on all three crewmembers on recovery day aboard the prime recovery vessel.

EQUIPMENT: Pulmonary function test equipment.

RESULTS: Postflight pulmonary function assessment was complicated by nitrogen tetroxide inhalation during recovery. Discomfort associated with deep inspiration and breath holding was noted R+1 and R+2. Parameters measured were: capacities (total lung, residual, vital, forced vital), flow rates (maximum expiratory, maximum midexpiratory, expiratory in 1 S), closing volume, closing capacity, single breath carbon monoxide diffusing capacity. Decreased diffusing capacity occurred until R+13 (50% in one crewman).

CONCLUSIONS: No significant postflight changes were observed when compared to the preflight means. The R+29 data obtained from the three crewmembers showed that the measured pulmonary function parameters, including DLCO<sub>SB</sub> and repeat blood gas determinations (breathing room air and 100% oxygen), were within normal limits.

PUBLICATIONS: 410, 464

PRINCIPAL INVESTIGATOR(S): W. Zachary Osborne, Lawrence S. Pinsky, and J. Vernon Bailey

EXPERIMENT TITLE/NUMBER: Apollo Light Flash Investigations

PROGRAM/MISSION: Apollo 15, 16, 17

CLASSIFICATION: Human

DISCIPLINE(S): Radiobiology

OBJECTIVES: To investigate the light flash phenomenon, and to obtain a direct physical record of incident cosmic ray particles.

PROTOCOL: There were 3 one-hour observation sessions for light flashes on Apollo 15, and 2 one-hour sessions on Apollo 16 and 17. On Apollo 16 and 17, the astronauts wore the ALFMED device during the mission while observing light flashes. Postflight analysis included: location scan, trajectory measurement, translation scan, correlation between observations and tracks, and charge and energy measurements.

EQUIPMENT: The ALFMED was an electromechanical helmet-like device that supported cosmic radiation-sensitive emulsions. A direct physical record was made of cosmic ray particles that passed through the emulsion plates and the subject's head.

RESULTS: On Apollo 7-10, no light flashes were detected. On Apollo 11, dark adapted crewmen "saw" light flashes with eyes open or closed. Subjective experience was 66% spot, 25% streak, and 8% cloud type flash. ALFMED result indicated cosmic radiation interaction with retina. Apollo 12-14 continued observations by all crewmen of light flashes. There was a correlation of light flashes with cosmic radiation of 50-300 MeV/nucleon.

CONCLUSIONS: Evidence shows that, at least in part, the flashes seen by astronauts are correlated with charged particles transversing the retina. Further, since the flux of these particles is sufficient to explain the entire phenomenon, it is likely that all of the flashes originate in this manner. The ALFMED technique has been demonstrated to be effective as a procedure for study of the light flash phenomenon.

PUBLICATIONS: 35, 111, 385, 412, 413, 426, 427, 428, 429

PRINCIPAL INVESTIGATOR(S): Paul C. Rambaut, Malcom C. Smith, and Harry O. Wheeler

EXPERIMENT TITLE/NUMBER: Nutritional Studies

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To study musculoskeletal changes, clinical disorders in space due to imbalance between bone formation and resorption, inflight weight loss, and inflight caloric intake.

PROTOCOL: The menu and caloric intake of the astronauts were carefully monitored. Food was analyzed for N, fat, carbohydrate, crude fiber, Ca, P, Fe, Na, K, and Mg. Body volume was measured by stereophotogrammetry, and total body water was calculated by K-42 dilution. Analysis was made of urine, blood, and fecal samples to study metabolic balance.

EQUIPMENT: Stereophotogrammetry apparatus.

RESULTS: Intake of potassium was monitored in Apollo for input and output. Less K was lost during flight than preflight. In Apollo 17, water consumption was lower during flight and urine output was lower. The insensible loss was 900-1200 cc/day, the same as preflight. There was a negative balance in phosphorus, and nitrogen during flight. A diminished nitrogen retention indicated a general musculoskeletal deterioration. Potassium retention inflight was less than that established during the control study. There was a mean body weight loss of 3.9 kg, and water loss of 1.77 liters. It was found that fat loss occurred rather than lean body loss. In Apollo 15, there were pronounced electrolyte anomalies. They may have been associated with inflight cardiac arrhythmias and postflight changes in exercise performance and cardiovascular responses.

CONCLUSIONS: Estimates of body composition changes from metabolic balance data provide no evidence for diminished caloric requirements during a flight. Measurements of bone density and metabolic balance confirm a tendency toward loss of skeletal tissue in weightlessness. No evidence exists that any inflight metabolic anomaly, including hypokalemia, was induced by marginal or deficient nutrient intakes. In general, the Apollo crewmen were well nourished and exhibited normal gastroenterological functions, although appetite was somewhat diminished and the organoleptic response to food was somewhat modified.

PUBLICATIONS: 240, 287, 357, 435, 438, 453, 483, 484, 487

PRINCIPAL INVESTIGATOR(S): Paul C. Rambaut, Malcolm C. Smith, Pauline E. Mack, and John M. Vogel

EXPERIMENT TITLE/NUMBER: Skeletal Response

PROGRAM/MISSION: Apollo 14, 15, 16

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To determine effects of weightlessness on bone during prolonged space flight.

PROTOCOL: A scan was made of the configuration of the heel os calcis and arm (radius and ulna) using a  $^{125}\text{I}$  source. It was made in 3 directions with a total of 4096 data points taken. Scans were made at F-1 month, F-2 weeks, F-1 week, and R+4. The bone scans were made using photon absorptiometry.

EQUIPMENT: Rectilinear bone mineral scanner,  $^{125}\text{I}$  source, NaI scintillator.

RESULTS: No mineral losses were observed in os calcis, radius, or ulna in Apollo 14. (There were significant increases in fat on the plantar side of the os calcis in the Command Module Pilot of Apollo 14.) In Apollo 15, there was some mineral loss in the bone, but none in Apollo 16. In all missions there was greater variation in mineral loss in the ulna. A significant change in the soft tissue composition of the Command Module Pilot in Apollo 14 was found, but none in Apollo 15 or 16.

CONCLUSIONS: Loss of mineral from bone incident to periods of weightlessness was comparable to that observed in bed rest subjects but the magnitude was not as severe. If these losses were allowed to continue unabated for a prolonged period of time, the consequences might be more serious since the losses were probably not confined to the bones described. Because of either biological variability between subjects or factors not yet identified, not all crewmen were similarly affected during the 10- to 12-day missions. These studies can be used to construct a time-effect curve that can be compared with the bed rest data, thus permitting a reasonable degree of prediction for longer space flight missions.

PUBLICATIONS: 370, 441, 535, 537, 540

PRINCIPAL INVESTIGATOR(S): Wayland J. Rippstein, and Howard J. Schneider

EXPERIMENT TITLE/NUMBER: Toxicological Aspects of Skylab Program

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To ensure a safe, habitable spacecraft environment for the crewmen.

PROTOCOL: A nonmetallic materials screening program was designed to eliminate those materials that would cause problems from their outgassed products. The screening program was based on measuring the amounts of carbon monoxide and total organics outgassed per unit weight of each candidate material. Levels of acceptance were established for both carbon monoxide and total organics based on the spacecraft habitable volume, the trace gas removal rate by the environmental control life support systems, and the cabin leak rate.

EQUIPMENT: Gas sampling equipment, mass spectrometer, gas chromatograph.

RESULTS: Results of analyses indicated the presence of approximately 300 compounds in the Orbital Workshop atmosphere. 107 of these compounds were identified.

CONCLUSIONS: The crew was provided with as safe an environment as could be attained using the current state-of-the-art trace gas removal technology. The knowledge gained in solving the trace contaminant problems encountered in the Skylab Program will greatly aid in providing safe, habitable spacecraft environments for the future missions of man in space.

PUBLICATIONS: 446, 447

PRINCIPAL INVESTIGATOR(S): John A. Rummel, Charles F. Sawin, and Edward L. Michel

EXPERIMENT TITLE/NUMBER: Exercise Response

PROGRAM/MISSION: Apollo 7-11, 14-17

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular, Respiratory, Behavioral Science

OBJECTIVES: To evaluate the physiological response to exercise pre- and postflight in order to assure the success of lunar surface extravehicular activity (EVA). This was not measured in space due to the redirected Apollo program after the Apollo fire.

PROTOCOL: A bicycle ergometer and graded stress protocol were utilized with heart rate determining stress levels. The protocol was comprised of exercise levels at heart rates of 120 (6 min.), 140 (3 min.), and 160 (3 min.). The tests were conducted three times within F-30 days, and at R+24 hours, and R+36 hours. The workload, heart rate, blood pressure, and respiratory gas exchange were measured every minute.

EQUIPMENT: Bicycle ergometer, graded stress equipment, LKG, respiratory gas exchange system.

RESULTS: Heart rate was increased in the immediate postflight test an average of 16 beat/min., but was not significantly elevated at the second test. The relationship between heart rate and oxygen consumption was significantly altered at all heart rate levels postflight. The blood pressure decreased postflight (both systolic and diastolic) at the same heart rate. There was a decrease in cardiac output (stroke volume) at the rate of 160 beat/min.

CONCLUSIONS: There was a decrease in stroke volume, which could have been caused by changes in circulating blood volume and/or redistribution of blood volume to lower extremities. There were no significant changes in mechanical or respiratory efficiencies. The heart rate was significantly elevated for the same oxygen consumption. This, in conjunction with the reduced stroke volume, maintained the same cardiac output/oxygen consumption relationship.

PUBLICATIONS: 64, 78, 82, 107, 456, 457, 458, 460

PRINCIPAL INVESTIGATOR(S): Charles F. Sawin, Arnaud E. Nicogossian, A. Paul Schachter, John A. Rummel, and Edward L. Michel

EXPERIMENT TITLE/NUMBER: Pulmonary Function Evaluation During and Following Skylab Space Flights

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Respiratory

OBJECTIVES: To evaluate the effects of space flight on pulmonary function.

PROTOCOL: Forced vital capacity was measured during the preflight and postflight periods of the Skylab 2 mission. Initial inflight measurements of vital capacity were obtained during the last two weeks of the second manned mission. Comprehensive pulmonary function screening was accomplished during the Skylab 4 mission. The primary measurements made during Skylab 4 testing included residual volume determination, closing volume, vital capacity and forced vital capacity and its derivatives. In addition, comprehensive inflight vital capacity measurements were made during Skylab 4.

EQUIPMENT: Analog tape recorder, differentiator, strip-chart recorder, digital voltmeter for nitrogen production, respiratory mass spectrometer, Skylab metabolic analyzer, XY plotter.

RESULTS: Pulmonary function assessment showed no change at R+24h. Parameters measured were: capacities (total lung, residual, vital, forced vital); flow rates (maximum expiratory, maximum midexpiratory, expiratory in 1 s); closing capacity, and closing volume. Inflight vital capacity was slightly reduced.

CONCLUSIONS: The vital capacity changes observed inflight may be partially explained as a response to 5 psia ambient pressure. However, the proportion of vital capacity decreases directly attributable to other factors such as body fluid shifts and a cephalad shift of the diaphragm cannot be determined from the present data. Regardless of the cause(s) of decreased inflight vital capacities, a review of postflight data shows that these changes revert to normal within two hours following recovery without significant impact on crew health status.

PUBLICATIONS: 464, 465, 466

PRINCIPAL INVESTIGATOR(S): Malcolm C. Smith and Rita M. Rapp

EXPERIMENT TITLE/NUMBER: Food and Nutrition

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To determine nutrient energy requirements.

PROTOCOL: Certain nutrients, in particular Na and K, were concentrated in those foods for which the crew displayed the highest preference and which were deemed most likely to be consumed. As much as possible of the minimum nutrient requirements were included in a basic diet of approximately 1800-2000 kilocalories (kcal). Preflight lean body mass was determined by measurement of total body <sup>40</sup>K in the low-background radiation counting facility at the NASA Lyndon B. Johnson Space Center. On the basis of Skylab energy consumption data and ASTP total body K measurements, the energy required to maintain LBM during the ASTP mission was predicted.

EQUIPMENT: None identified.

RESULTS: Estimates of in-flight food consumption based on daily reports indicate that averages of 2900, 3000, and 2867 kcal/day were consumed by the ACDR, the CMP, and the DMP, respectively. No gastrointestinal problems were encountered during the mission. Appetites during flight were reported to be the same as during the preflight period. The CMP reported changes in the taste of foods during flight and indicated that salty foods tasted best to him. As on previous Apollo missions, the crew reported gas in the hot water supply which interfered with complete rehydration of the food. Throughout the mission, high-priority activities and work schedules frequently precluded adequate time for meal preparation and food consumption.

CONCLUSIONS: In general, the crew was satisfied with the quality and quantity of flight food provided.

PUBLICATIONS: 486

PRINCIPAL INVESTIGATOR(S): Raphael F. Smith, Kevin Stanton, David Stoop,  
Donald Brown, Walter Janusz, and Paul King

EXPERIMENT TITLE/NUMBER: Vectorcardiographic Changes During Extended Space  
Flight, MC93

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To measure electrocardiographic signals during space flight, to elucidate the electrophysiological basis for the changes observed, and to assess the effect of the change on the human cardiovascular system.

PROTOCOL: Vectorcardiograms were taken at rest, during and after exercise in each crewman in the preflight, inflight, and postflight phases. The crew exercised on the bicycle ergometer at a work load of 150 watts for 2 min, and then vectorcardiograms were obtained for 10 min.

EQUIPMENT: Vectorcardiograph, bicycle ergometer.

RESULTS: There was a statistically significant increase in QRS vector magnitude, T maximum vector magnitude, and resting PR interval. During exercise, the PR interval did not differ from preflight. Exercise heart rates inflight were the same as preflight, but increased in the immediate postflight period. No major changes in QRS, T, or ST vector direction occurred. During the three flights cardiac arrhythmias were occasionally observed.

CONCLUSIONS: With the exception of the arrhythmias, no adverse electrocardiographic changes were observed during the Skylab missions. The increase in QRS and T magnitude resembles the electrocardiographic changes associated with athletic conditioning and may be related to increased ventricular volume secondary to centripetal shifts of fluid and/or the inflight isotonic exercise program. Prolongation of the PR interval at rest with normalization by exercise suggests that there was increased vagal tone in those crewmen exhibiting this response.

PUBLICATIONS: 489, 490, 491, 492, 493

PRINCIPAL INVESTIGATOR(S): Gerald R. Taylor

EXPERIMENT TITLE/NUMBER: Medical Microbiological Analysis of U. S. Crewmembers

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Environmental health

OBJECTIVES: To identify and trace all microorganisms of potential medical importance.

PROTOCOL: Nine sets of specimens were collected from the three prime Apollo crewmembers on days F-45, F-30, F-15, and F-7, and on launch day; once during flight; on recovery days R+0, R+15, and R+30. Inflight samples were obtained from all five flight crewmembers on both spacecraft. During each preflight and postflight sample period, microbial specimens were collected from 10 sampling sites on each crewmember. Calcium alginate swabs wetted in 0.3M phosphate buffer were used to sample each of the seven body surface areas. Dry calcium alginate swabs were used to sample the surfaces of the tonsils and the posterior pharyngeal vault before collection of the gargle specimen.

EQUIPMENT: Microbial sample collection device.

RESULTS: Although several potential pathogens were recovered from each of the flight and backup crewmembers before and after flight, no disease events were reported. Candida albicans and Staphylococcus aureus were shown to have been transferred from one crewmember to another during flight.

CONCLUSIONS: There were no medically significant changes in the microbial population, nor were any long-term hazards noted.

PUBLICATIONS: 506, 507, 508, 510

PRINCIPAL INVESTIGATOR(S): Gerald R. Taylor, Kathryn D. Kropp, Mary R. Henney, Suzanne S. Ekblad, Anwar A. Baky, Theron O. Groves, Thomas C. Molina, Jean G. Decelle, Carolyn F. Carmichael, Nina J. Gehring, E. Landrum Young, I. L. Shannon, William J. Frome, and N. R. Funderburk

EXPERIMENT TITLE/NUMBER: Microbial Exchange, AR-002

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human. Microorganism

DISCIPLINE(S): Environmental health

OBJECTIVES: To evaluate components of the infectious disease process in space flight by measuring alterations in the composition of the microbial populations inhabiting the crewmembers and spacecraft, the ability of each crewmember's defense mechanism to resist infection, and the ability of certain microorganisms to originate infections.

PROTOCOL: Sample specimens were collected from 10 sites on the Apollo and Soyuz crewmembers and from 15 areas on the inner surfaces of each spacecraft at specific times pre-, inflight, and postflight. Saliva and blood samples were also collected pre- and postflight. Analyses included dilution and plating of specimen materials, isolation of microbial colonies, and evaluation of growth properties on the initial isolation media.

EQUIPMENT: Microbial collection and storage device.

RESULTS: A variety of potential pathogens was recovered from each of the crewmembers pre- and postflight. However, no disease events were reported. Candida albicans and Staphylococcus aureus were shown to be transferred from one crewmember to another during flight. No other medically significant changes were observed.

CONCLUSIONS: The proposed simplification of the population of medically important microorganisms, and the theorized postflight microbial shock could not be supported by the results of this study.

PUBLICATIONS: 511, 512

PRINCIPAL INVESTIGATOR(S): Gerald R. Taylor, Royce M. Brockett, James K. Ferguson, Richard C. Graves, and Bernard J. Mieszkuc

EXPERIMENT TITLE/NUMBER: Skylab Environmental and Crew Microbiology Studies

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Environment, health

OBJECTIVES: To detect the presence of potentially pathogenic microorganisms on the crewmembers and their spacecraft and to obtain data which would contribute to an understanding of the response of the crew's microbial flora to the space environment.

PROTOCOL: Microbial flora samples were collected from selected sites in Orbital Workshop, Command Modul, on crew body surfaces and from urine and feces, preflight, inflight, and postflight.

EQUIPMENT: Calcium alginate swabs.

RESULTS: Approximately 10,000 microbial isolations were obtained, identified and characterized. Variation occurred in microbial response because of ecological relationships, host susceptibility and external environmental factors. Spread of pathogens between crewmen was common. While the total number of aerobes was found to increase, the species and number of anaerobes decreased.

CONCLUSIONS: Data showed that, while gross contamination of the Skylab environment was demonstrated and there were several inflight disease events, such events are not limiting hazards for long term manned space flights. Intercrew transfer of pathogens was demonstrated, although evidence of postflight microbial shock was not found.

PUBLICATIONS: 88, 517

**PRINCIPAL INVESTIGATOR(S):** William E. Thornton, G. Wyckliffe Hoffler, and John A. Rummel

**EXPERIMENT TITLE/NUMBER:** Anthropometric Changes and Fluid Shifts

**PROGRAM/MISSION:** Skylab 4

**CLASSIFICATION:** Human

**DISCIPLINE(S):** Cardiovascular

**OBJECTIVES:** To obtain a comprehensive and coherent picture of changes in size, shape, and composition of the human body in weightlessness.

**PROTOCOL:** Nine anthropometric measurements were made at various body locations preflight, and postflight. A series of preflight, inflight, and postflight photographs were made with the crewmen in standard anatomical position. An infrared sensitive color film was used to show superficial venous blood distribution. Center of mass and center of gravity measurements were made to indicate fluid shifts.

**EQUIPMENT:** Calibrated tape jig, infrared film (35 mm), camera, center-of-mass measurement device.

**RESULTS:** Inflight, the spinal column was flexed with loss of the thoracolumbar curve but retention of cervical curvature, so that the head was thrust forward. Postflight, little change was found from preflight posture. There was an inflight increase in height, a loss of abdominal girth, and a large and rapid fluid shift from the lower to upper body. The center of mass shifted cephalad more than could be accounted for by the height increase. Photographs provided evidence for increased fluid in the head and neck region. The fluid shifts reversed quickly after recovery.

**CONCLUSIONS:** It is hypothesized that the driving force for the fluid shift is the intrinsic and unopposed lower limb elasticity that forces venous blood and then other fluid cephalad. This shift may be the driving force for a number of other phenomena including blood volume loss, changes in leg hemodynamics, and vestibular dysfunction.

**PUBLICATIONS:** 520, 521

PRINCIPAL INVESTIGATOR(S): William E. Thornton, and G. Wyckliffe Hoffler

EXPERIMENT TITLE/NUMBER: Hemodynamic Studies of the Legs Under Weightlessness

PROGRAM/MISSION: Skylab 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To investigate the hemodynamic mechanisms involved in the alterations in the return of blood from the legs after weightlessness which play a crucial role in orthostatic tolerance.

PROTOCOL: Venous compliance and arterial blood flow were determined by occluding venous flow with a pressure cuff above the knee and recording the resulting change in volume from a midcuff segment. Muscle pumping action was studied by placing the subject in lower body negative pressure at -30 mmHg and recording volume change from a calf segment. The studies were performed 3 times preflight, 7 times inflight, and 3 times postflight.

EQUIPMENT: Capacitance volume transducer, lower body negative pressure device.

RESULTS: There was an increase in blood flow in all crewmen inflight, but there were no apparent trends. After flight there was an immediate sharp reduction, almost to preflight values. Venous compliance showed a gradual increase which reached a factor of five in 2 of the 3 crewmen by mission day 15, a slowly decreasing trend in all three crewmen after mission day 40, and a sharp drop to less than preflight values at recovery. After muscle pumping under negative pressure, the relative amount of blood remaining in leg veins was about the same during flight as before flight, but the absolute amount collected and remaining was increased several times.

CONCLUSIONS: The most likely cause of increased blood flow was an increase in the cardiac output secondary to increasing central venous pressure caused by blood redistribution. Changes in the venous compliance are thought to be primarily changes in the somatic musculature which is postulated to primarily determine venous compliance of the legs. This was also thought to be demonstrated by the changes in muscle pumping. It is thought that these compliance changes, when taken with the decreased blood volume, provide a basis for the changes seen in orthostatic tolerance, work capacity, and lower body negative pressure response.

PUBLICATIONS: 522, 523

PRINCIPAL INVESTIGATOR(S): William E. Thornton, and John A. Rummel

EXPERIMENT TITLE/NUMBER: Muscular Deconditioning and its Prevention in Space Flight

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To prevent muscular deconditioning in space.

PROTOCOL: Atrophy of weight-bearing muscular groups was measured with a constant speed dynamometer. Ten maximum effort, full-range flexions/extension of the arm at the elbow and of the hip and knee at 45 degrees/second were recorded and evaluated for each crewman pre- and postflight. Anthropometric measurements allowed computation of volume changes in limb segments. A bicycle ergometer and an isometric exercise device were used throughout the missions for exercise, as well as a simulated treadmill which provided 170 pounds equivalent weight.

EQUIPMENT: Constant speed dynamometer, bicycle ergometer, isometric device, treadmill (consisting of a Teflon walking surface, a harness, and elastic bungees), mini gym.

RESULTS: The flight crew returned in good condition. Slight losses in muscle function of arms or legs were measured.

CONCLUSIONS: Muscle in space is no different from muscle on Earth. If it is properly nourished and exercised at reasonable load levels, it will maintain its function. Future research efforts should focus on optimum methods of exercise with respect to crew time and crew acceptance, interrelationship of musculoskeletal fitness with cardiovascular fitness, and design of practical, efficient, total body exercises.

PUBLICATIONS: 524, 525

PRINCIPAL INVESTIGATOR(S): William E. Thornton, and John W. Ord

EXPERIMENT TITLE/NUMBER: Physiological Mass Measurements in Skylab

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To determine the cause and time course of weight loss by making controlled daily intake/output mass measurements in flight.

PROTOCOL: The Body Mass Measurement Device (BMMD), with a capacity of 100 kilograms, was used to make a basal body mass measurement on each crewman every morning in flight. The Specimen Mass Measurement Device (SMMD), with a range of 50-1000 grams, was used to measure the mass of food residue, feces, and vomitus. These devices utilized the inertial property of mass rather than gravitational force to determine mass.

EQUIPMENT: Body Mass Measurement Device (BMMD), Specimen Mass Measurement Device (SMMD).

RESULTS: Two general patterns of body mass loss were apparent. There was a continuous loss beginning preflight with an increase in rate of loss in flight. A second is indicated by relative stability except for a small loss during the first days of weightlessness with a reciprocal gain during the first few days postflight. A surprisingly high metabolic loss was present in all crewmen except one, and a small fluid loss (on the order of a liter), appeared to occur during the initial few days of weightlessness followed by a reciprocal change on return. This loss was small and self-limited, and appeared to be the only obligatory loss, the other losses being primarily metabolic.

CONCLUSIONS: This experiment demonstrated a new instrument for in flight space operations and research. Previously unproven mechanisms of weight loss under weightlessness were demonstrated. The human body properly fed can be sustained through missions of long duration without significant obligatory loss of mass.

PUBLICATIONS: 526, 527, 528

PRINCIPAL INVESTIGATOR(S): John M. Vogel, Michael W. Whittle, Malcolm C. Smith, and Paul C. Rambaut

EXPERIMENT TITLE/NUMBER: Bone Mineral Measurement, M078

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To assess the effects of the spaceflight environment on the occurrence and degree of bone mineral changes.

PROTOCOL: The photon absorptiometric technique was used to determine bone mineral content in the central left os calcis and the right distal radius and ulna. An essentially monoenergetic photon source, the 27.5 KeV X-ray of  $^{125}\text{I}$ , and a sodium iodide crystal scintillation detector were used. They were mounted on a scanner yoke which scanned the limb placed between the source and detector.

EQUIPMENT: A scanning apparatus, gamma ray detector, multichannel analyzer.

RESULTS: No significant mineral losses were observed in any of the Skylab 2 crew. Only the Scientist Pilot of Skylab 3 and 4, and the Pilot of Skylab 4 had significant mineral losses in the os calcis. No losses in the radius and ulna were seen. The losses observed generally followed the loss pattern observed in a heterogeneous group of bedrest subjects.

CONCLUSIONS: Mineral losses from the bones of the lower extremities occurred during missions of up to 84 days and they followed the loss patterns of bedrest situations. The levels of loss observed in the Skylab crews were of no clinical concern.

PUBLICATIONS: 485, 536, 537, 538, 539

PRINCIPAL INVESTIGATOR(S): James M. Waligora, and David J. Horrigan

EXPERIMENT TITLE/NUMBER: Metabolic Cost of Extravehicular Activities

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular, Behavioral science

OBJECTIVES: To measure metabolic rates during extravehicular activities.

PROTOCOL: Using a thermoregulatory mathematical model and empirical data on the liquid-cooled garment, a relationship was defined between liquid-cooled garment heat removal and metabolic rate for each liquid-cooled garment inlet temperature. Correlations between heart rate and metabolic rate were obtained for each individual from a series of preflight exercise response tests on the ergometer. The heart rate method was used only as a relative measurement because of its known sensitivity to psychological and environmental factors.

EQUIPMENT: Life support equipment.

RESULTS: The metabolic rates were similar to those on the Apollo 1/6-g extravehicular activities. The highest metabolic rate, 500 kcal/h, was reached while the Commander on Skylab 2 was trying to cut a strap that was keeping the solar panels from deployment. The lowest rates were resting rates and these were reached several times during the extravehicular activities, particularly at the times when there was not enough light to continue an ongoing activity during a night pass. Crew comments during extravehicular activities indicated that it was easier to maneuver themselves and their equipment in zero-g than in water tank simulations, but that adequate restraints were more important.

CONCLUSIONS: With adequate life support equipment and restraints, the capability was demonstrated to perform varied and complex extravehicular activity tasks in zero-g with considerable real-time flexibility.

The capability to work at relatively high levels, up to 500 kcal/h when required, was demonstrated without physiologic problems provided life support capability is adequate.

The average energy cost of long extravehicular activities was remarkably consistent at about 200 to 250 kcal/h, and appeared to be a function of the crew pacing its activity rather than to the effort involved in performing individual tasks.

PUBLICATIONS: 284, 552, 553, 554, 555

PRINCIPAL INVESTIGATOR(S): James M. Waligora, and David J. Horrigan

EXPERIMENT TITLE/NUMBER: Metabolism and Heat Dissipation During Apollo EVA  
Periods

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular, Behavioral science

OBJECTIVES: To determine the life support requirements during extravehicular activity (EVA).

PROTOCOL: Metabolic rate was determined by measuring heart rate, oxygen usage, and coolant water temperature change. These, as well as body heat and other physiological parameters were measured as the astronauts participated in these four types of EVA: overhead activities, deploying Apollo lunar surface experiment packages, making geological surveys, and riding in the lunar roving vehicle.

EQUIPMENT: Pressure suit, liquid cooling garment (LCG).

RESULTS: Metabolic rates were lower than expected for Apollo EVA. Overhead activities were the most energy consuming tasks performed. The highest metabolic rate was in the Apollo 11 LMP, who was very active in evaluating modes of locomotion. The lowest metabolic rates occurred while astronauts drove and rode in the lunar roving vehicle. Data from Apollo 14 showed poor correlation between lunar walking speed and metabolic rate. Results from observations of Apollo 15 and 16 time and motion studies indicated that tasks were completed more rapidly at one-g wearing the space suit than at 1/6-g, but at a higher metabolic rate.

CONCLUSIONS: The crewmen were able to perform EVA and to extend them to the maximum time without medical problems. Metabolic rates were lower than predicted. The liquid cooling garment was effectively used.

PUBLICATIONS: 82, 460, 551, 554, 555

PRINCIPAL INVESTIGATOR(S): G. Donald Whedon, Leo Lutwak, William F. Neuman,  
and Paul A. LaChance

EXPERIMENT TITLE/NUMBER: Calcium and Nitrogen Balance, M007

PROGRAM/MISSION: Gemini 7

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To collect data on the effects of a 14-day space flight on two of the largest metabolically active tissue masses of the human body, the bones and the muscles.

PROTOCOL: By use of the metabolic-balance method, which involved precise control of dietary intake and collection and analysis of all excreta, it was possible to obtain a quantitative determination of the extent of change in the principal inorganic constituents of the skeletal and muscular systems. The extent of loss of inorganic constituents generally was proportional to the extent of functional deterioration. Complete metabolic balance studies were made measuring intake and excretion of calcium, magnesium, phosphate, sulphate, nitrogen, sodium, potassium and chloride.

EQUIPMENT: Urine collection device.

RESULTS: Urinary phosphate excretion increased substantially inflight despite a reduction of phosphate intake. Urinary nitrogen and sulfate excretion decreased inflight to a lesser extent than would be expected from the reduction in intake. Patterns of excretion of magnesium, sodium, potassium, and chloride were different for each subject, and in part, could be correlated with changes in adrenocortical steroid production. The principal hormonal change was a striking decrease during flight in the urinary excretion of 17-hydroxycorticosteroids. Dermal losses of calcium, magnesium, sulfate, nitrogen, and phosphate were insignificant during all three phases.

CONCLUSIONS: The changes in calcium metabolism and in other factors were moderate enough to support (from the metabolic viewpoint) the decision that a voyage to and from the Moon would be safe medically, because the time involved would be no more (in fact, less) than was involved on the Gemini VII mission. However, for assessment of the physiological safety and performance of astronauts on future much longer flights, the necessity is evident for additional inflight metabolic observations. These observations must be planned with better control, despite operational constraints. Such studies will result in more reliable information for accurate prediction of the extent of mineral and other metabolic changes to be expected in long-duration space flight and will result in the establishment of a basis for judgment of the necessity for development and assessment of corrective or protective measures.

PUBLICATIONS: 358, 359, 360, 361, 362, 560, 561, 562, 563, 564, 565

PRINCIPAL INVESTIGATOR(S): G. Donald Whedon, Leo Lutwak, Paul C. Rambaut, Michael W. Whittle, Malcolm C. Smith, Jeanne Reid, Carolyn S. Leach, Connie R. Stadler, and Deanna D. Sanford

EXPERIMENT TITLE/NUMBER: Mineral and Nitrogen Metabolic Studies, M071

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To determine major changes in the chemical state of the muscular and skeletal systems under space flight conditions.

PROTOCOL: The study required constant dietary intake, continuous 24-hour urine and total fecal collection for 21 to 31 days preflight, inflight, and through R+17-18.

EQUIPMENT: Urine measurement and collection system, fecal collection system, Specimen Mass Measurement Device (SMMD).

RESULTS: The average 24-hour urinary creatinine excretion was not changed by space flight. Increases in urinary calcium were similar to those in bedrest studies. Increased excretion of nitrogen and phosphorus reflected substantial loss of muscle tissue. Both muscle and mineral loss occurred despite an exercise regimen on all flights.

CONCLUSIONS: Unless protective measures can be developed, capable musculo-skeletal function is likely to be impaired in space flights ultimately to be conducted to Mars, of one and one-half to three years duration.

PUBLICATIONS: 561, 563, 564, 565, 566, 567, 568

C-2

PRINCIPAL INVESTIGATOR(S): Michael W. Whittle, Robin E. Herron, and Jaime R. Cuzzi

EXPERIMENT TITLE/NUMBER: Biostereometric Analysis of Body Form

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human

DISCIPLINE(S): Cardiovascular, Musculoskeletal

OBJECTIVES: To measure the effects of space flight on body form.

PROTOCOL: The subjects were photographed simultaneously by two cameras in front and two behind. A strobe projector projected a pattern of lines on the subject's skin. After development, photographic plates were analyzed on a stereoplotter, which derived the three-dimensional coordinates of thousands of points on the body surface, punching them on IBM cards for subsequent computer analysis. The computer program derived area, shape, and perimeter of between 80 to 100 sections of different parts of the body, and volume of any segment of the body, and of the body as a whole.

EQUIPMENT: Four Hasselblad cameras, stereoplotter, strobe projector.

RESULTS: There was no statistically significant difference in mean arm volume between preflight and postflight measurements. Mean losses of volume of 1.2 liters in the head and trunk, and 1.3 liters in the legs were found. Post-flight change in volume was proportionately much greater in the legs than in the head and trunk. Marked loss of volume was seen in the abdomen, buttocks, and calves, and a less striking loss in the thighs.

CONCLUSIONS: During flight there was a reduction in body fluid, a partial muscle atrophy, particularly in the legs, and in all but two of the crewmen, a loss of body fat. The partial muscle atrophy probably resulted from relative disuse in the absence of gravity and was lessened to some extent by the inflight exercise program.

PUBLICATIONS: 570, 571, 572, 573, 574

PRINCIPAL INVESTIGATOR(S):

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Mercury 3, MR-3

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To familiarize man with a brief but complete space flight experience, to evaluate man's ability to perform as a functional unit during spaceflight, and to study man's physiological reactions.

PROTOCOL: A pre- and postflight physical examination was performed, which included a psychiatric interview. Routine blood and urine studies were performed at F-3 hours, and R+45 min. Micromethods were utilized when possible to analyze the samples. Parameters measured inflight were heart rate, body temperature, and respiration.

EQUIPMENT: Linear potentiometer with carbon-impregnated rubber (indirect respiration measurement), rectal thermister (body temperature), EKG with low impedance electrodes (for heart rate), camera (to film astronaut).

RESULTS: No disturbing sensations were noted during weightlessness and astronaut physiological function appeared in no way to be impaired. Acceleration launch and re-entry g-forces produced stress magnitudes consistent with those encountered during the training programs.

CONCLUSIONS: Physiological responses were consistent with intact conscious performance during all phases of flight. Responses to 5 minutes of weightlessness were uneventful. The relative change in pulse rate in going from weightlessness to re-entry acceleration was comparable to that in going from 1-g to re-entry acceleration on the centrifuge. Vision, semicircular canal function, and hearing appeared intact throughout the flight.

PUBLICATIONS: 14, 260, 289, 351, 570

PRINCIPAL INVESTIGATOR(S):

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Mercury 4, MR-4

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To familiarize man with a brief but complete space flight experience, to evaluate man's ability to perform as a functional unit during space flight, and to study man's physiological reactions.

PROTOCOL: Astronaut was given a complete physical examination on F-10 and F-3, and a brief examination on the day of the flight. An examination was also given on recovery. Several parameters were monitored inflight, including heart rate, body temperature, and respiration. Urine was collected for post-flight analysis. One week preflight, the astronaut was placed on a controlled diet and on F-3 was placed on a low residue diet. A continuous record was made of what the astronaut was doing during the flight.

EQUIPMENT: Linear potentiometer with carbon impregnated rubber (indirect respiration measurement), rectal thermistor (body temperature), EKG with low impedance electrodes (for heart rate). No measurement was made of blood pressure or of radiation exposure since the spacecraft was going below the Van Allen belts.

RESULTS: All physiological readings were normal. Peak responses were maintained at critical inflight events. There was no evidence of motion sickness, and no indication of body system dysfunction.

CONCLUSIONS: There were no adverse physiological effects associated with space flight, but further investigations are needed.

PUBLICATIONS: 351

**PRINCIPAL INVESTIGATOR(S):**

**EXPERIMENT TITLE/NUMBER:**

**PROGRAM/MISSION:** Mercury 6, MA-6

**CLASSIFICATION:** Human

**DISCIPLINE(S):** Environmental health

**OBJECTIVES:** To evaluate the performance of a man-spacecraft system in a three-pass orbital mission, to evaluate the effects of space flight on the astronaut, and to obtain the astronaut's evaluation of the operational suitability of the spacecraft and supporting systems for manned space flight.

**PROTOCOL:** Pre- and postflight physical examinations were performed including a balance test, caloric irrigation to find the threshold temperature for nystagmus, and a psychiatric interview. Routine blood and urine tests were made. Gastrointestinal function was measured by xylose absorption.

**EQUIPMENT:** Linear potentiometer with carbon-impregnated rubber (indirect respiration measurement), rectal thermistor (body temperature), EKG with low impedance electrodes (heart rate), blood pressure measuring system, inflight urine collection devices.

**RESULTS:** No gastrointestinal, vestibular, or disorientation symptoms were noted during weightlessness. There were no adverse effects from isolation or confinement. No significant changes from the pilots preflight condition were revealed. A mild dehydration was observed.

**CONCLUSIONS:** The physiological responses observed were all consistent with intact systems and normal body functions. This exposure to weightlessness was of sufficient duration to permit physiological responses to reach a relatively steady state. Acceleration-weightlessness transition periods did not produce any recognized physiological deterioration. The environmental control system effectively supported the pilot throughout the mission.

**PUBLICATIONS:** 129, 304, 332, 351, 401

PRINCIPAL INVESTIGATOR(S):

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Mercury 7, MA-7

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To evaluate the performance of the man-spacecraft system in a three-pass orbital mission, to evaluate the effects of space flight on the astronaut, and to obtain the astronaut's opinions on the operational suitability of the spacecraft systems.

PROTOCOL: Pre- and postflight physical examinations were performed which included routine and special laboratory tests, X-rays, retinal photography, electrocardiography, electroencephalography, and special tests of the body's balancing mechanism. A xylose tolerance test was performed inflight.

EQUIPMENT: Two sets of EKG leads, rectal temperature thermistor, respiration rate thermistor, blood pressure measuring system, inflight urine collection device.

RESULTS: No pulmonary atelectasis, no cosmic ray damage, nor any psychiatric abnormalities were found. There were no abnormal vestibular or related gastrointestinal symptoms. Biochemical analysis confirmed the occurrence of a moderate diuresis.

CONCLUSIONS: All flight responses were considered to be within acceptable physiological ranges. No disturbing body sensations were reported as a result of weightlessness.

PUBLICATIONS: 351, 383, 402

PRINCIPAL INVESTIGATOR(S):

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Mercury 8, MA-8

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To evaluate the performance of the man-spacecraft system in a six-pass orbital mission, to evaluate the effects of an extended orbital space flight on the astronaut and to compare this analysis with those of previous missions and astronaut-simulator programs and to obtain additional astronaut evaluation of the operational suitability of the spacecraft and support systems.

PROTOCOL: Pre- and postflight physical examinations were performed which included routine and special laboratory tests, X-rays, electrocardiography, electroencephalography, the modified caloric test, radiation dosimetry, retinal photography, biochemical and plasma enzyme studies.

EQUIPMENT: Two sets of EKG leads, rectal temperature thermistor, impedance pneumograph, blood pressure measuring system, inflight urine collection device.

RESULTS: An orthostatic rise in heart rate, fall in systolic blood pressure, and maintenance of the diastolic pressure was noted during R+24 hour examinations. Lability of instantaneous heart rate was found and was not associated with respiration or other known physical activity. Radiation exposure was minimal and posed no hazard to flight. The inflight orientation test demonstrated no impairment of performance.

CONCLUSIONS: There was no evidence of disorientation or related untoward symptoms. There were no significant medical abnormalities nor medical contraindications to embarking on a longer mission.

PUBLICATIONS: 43, 351

PRINCIPAL INVESTIGATOR(S):

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Mercury 9, MA-9

CLASSIFICATION: Human

DISCIPLINE(S): Environmental health

OBJECTIVES: To evaluate the effects on the astronaut of approximately one day of orbital flight, to verify that man can function for an extended period in space as a primary operating system of the spacecraft, and to evaluate the combined performance of the astronaut and a Mercury spacecraft specifically modified for the mission.

PROTOCOL: Pre- and postflight physical examinations were performed which included routine and special laboratory tests, X-rays, electrocardiography, electroencephalography, the modified caloric test, radiation dosimetry, retinal photography, biochemical and plasma enzyme studies.

EQUIPMENT: Two sets of EKG leads, rectal temperature thermistor, impedance pneumograph, blood pressure monitoring system, inflight urine collection device.

RESULTS: There was no evidence of degradation in the functional integrity of the crewmember as a pilot. Orthostatic hypotension accompanied by an accelerated pulse response and dehydration were found postflight. A reversal of the ratio between neutrophils and lymphocytes was noted in the peripheral blood at R+4 and continued until R+14.

CONCLUSIONS: The medical status of the pilot was essentially unchanged between preflight and postflight examinations. No evidence of abnormal sensory, psychiatric, or psychological response to orbital space flight was found.

PUBLICATIONS: 44, 129, 351

PRINCIPAL INVESTIGATOR(S): John H. Able, David W. Haack, and Richard W. Price

EXPERIMENT TITLE/NUMBER: Effects of Weightlessness on the Nutrition and Growth of Pelomyxa carolinensis, P-1035

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal - Amoeba (Pelomyxa carolinensis)

DISCIPLINE(S): Cell biology

OBJECTIVES: 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.

PROTOCOL: The amoebae were cultured and subcultured, placed in a buffer and fed paramecium. Five complete units of 24 chambers were assembled 2 days before launch. The organisms were loaded at F-18.3 hr. The amoebae were screened and counted as they were selected for the chambers. After the amoebae and paramecium were loaded, the chambers were filled with THAM glycyl glycine buffer, with a small airspace left. The fixations were actuated 5 times inflight. At recovery, the organisms were counted, examined for mitotic forms, food vacuoles counted and the gross morphology described.

EQUIPMENT: Experiment package with 24 chambers, each divided into three 5-ml compartments containing either amoebae, paramecium or fixative. The chambers were mounted on magnesium plates. Four of the chambers contained thermistors.

RESULTS: The amoebae fed normally while in orbit, and specimens fixed in orbit retained the ordinary heteropodal shape. Growth rates of orbited amoebae, both fed and starved, were slower than controls following reentry and recovery procedures. In continuous-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.

CONCLUSIONS: The weightless environment did not produce any gross irreversible alterations in the normal physiologic processes of the amoebae.

PUBLICATIONS: 1, 431

PRINCIPAL INVESTIGATOR(S): W. Ross Adey, and P. M. Hahn

EXPERIMENT TITLE/NUMBER: Biosatellite III Results

PROGRAM/MISSION: Biosatellite III

CLASSIFICATION: Animal - Pig-tailed monkey (Macaca nemestrina)

DISCIPLINE(S): Neurosensory, Behavioral science, Musculoskeletal, Urogenital, Chronobiology

OBJECTIVES: To create a small laboratory with a single environmental shift which cannot be duplicated on earth (weightlessness) and observe the physiological effects on a pig-tailed monkey.

PROTOCOL: The animal was surgically implanted with deep-brain electrodes and thermistors, two arterial and two venous vascular catheters and a suprapubic urethral catheter in order to obtain neurophysiological, cardiovascular, and renal function data. Subcutaneous electrodes were used to obtain ECG and ZPN data. The animal was also trained to perform a series of psychomotor performance tasks during the flight. Additional preflight and postflight studies included assessments of body composition, skeletal mineral and hematological effects of long-duration space flight.

EQUIPMENT: Bipolar electroencephalograph electrodes, electrooculographic sensors, electromyographic leads, heart function and respiration sensors, vascular catheters, temperature sensors in brain and peritoneal cavity, urinary catheter, transducers, life support system, visuomotor and delayed matching task equipment.

RESULTS: The mission was terminated on the ninth mission day after telemetered data indicated significant physical deterioration of the animal. The animal died approximately 8 hours after recovery. The acute cause of death was ventricular fibrillation. Data telemetered during the flight indicated significant (2-3 cm H<sub>2</sub>O) elevations in central venous pressure coupled with normal arterial pressures and heart rates. EEG data showed a progressive deterioration in cortical function through the latter half of the flight. Temperature, heart rate and respiration data showed a desynchronization with periods of greater than 24 hours. Blood pressure rhythms were not larger than 24 hours. Autopsy (10 hours after death) showed a bruised spot on the heart, petechial hemorrhages in the ileum, congestion and edema of the lungs, and thrombi in the circulatory system.

CONCLUSIONS: It was surmised that the deterioration in the physical condition of the animal prior to recovery was due to dehydration and an associated electrolyte imbalance.

PUBLICATIONS: 2, 4, 7, 369

PRINCIPAL INVESTIGATOR(S): R. E. Allen, G. H. Barlow, Milan Bjer, P. E. Bigazzi, R. J. Knox, F. J. Micale, G. V. F. Seaman, J. W. Vanderhoff, C. J. Van Oss, W. J. Patterson, F. E. Scott, P. H. Rhodes, B. H. Nerren, and R. I. Harwell

EXPERIMENT TITLE/NUMBER: Electrophoresis Technology, MA-011

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human, Animal

DISCIPLINE(S): Cell biology

OBJECTIVES: To conduct engineering and operational tests of a space-rated static electrophoresis separation apparatus and to further current research efforts through separation of similar cellular species.

PROTOCOL: An electrophoresis or isotachopheresis column was removed from its storage location and installed in the electrophoresis unit in space. Fluid couplings were secured to each electrode chamber of the electrophoresis columns only. The slide containing a specific frozen sample was next removed from the cryogenic freezer and inserted into the column. A camera mounted on the electrophoresis unit cover photographed critical control positions and digital readouts during each column operation. Following each electrophoresis separation, the electrophoresis columns were frozen by the thermoelectric module and then removed from the cradle. The crewman then removed each electrode chamber from the columns and placed the column in the cryogenic freezer for return to Earth. The isotachopheresis columns were neither frozen nor returned, but only photographed in orbit during their operation.

EQUIPMENT: An electrophoresis unit, a cryogenic freezer, eight experiment columns (six electrophoresis, two isotachopheresis), and eight sample insertion slides.

RESULTS: Separation of human, rabbit and horse erythrocytes was accomplished. Human kidney cells could be concentrated into urokinase (UK), human granulocyte conditioning factor (HGCF) and erythropoietin fractions. Human lymphocytes were inconclusive. For the isotachopheresis part of the experiment, separation of human erythrocytes from hemoglobin or dyes was achieved. Separation of human and rabbit erythrocytes or rabbit and sheep erythrocytes was not achieved.

CONCLUSIONS: With the success of separation of the standard particles, it was shown that electrophoresis can be performed under zero-g conditions. The absence of significant electro-osmosis, the loading and returning of a sterile system, the capture of the resulting separation, and the preservation of

the viable cells in orbit and during the subsequent return represents many "firsts" for space. The newer methods of separation by isotachopheresis proved the feasibility of conducting large-particle processing by this method. Unfortunately, the experiment was not totally successful because the fluid lines in some of the columns were blocked.

PUBLICATIONS: 10, 11, 12, 25, 83, 84, 473

PRINCIPAL INVESTIGATOR(S): E. R. Ballinger, and James P. Henry

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Aerobee 2

CLASSIFICATION: Animal - Rhesus monkey (Macaca mulatta), Mice

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To study the physiological effects of weightlessness.

PROTOCOL: The monkey was anesthetized while the mice were not. They were taken to a height of 236,000 ft. Heart rate, respiration, arterial and central venous pressures were measured. Nine mice were placed in a separate compartment to study effects of cosmic radiation. Two mice were placed in a separate drum rotating at 12 rpm. One mouse was normal and one was labyrinthectomized. The mice had to climb over a small paddle while performance was recorded on film.

EQUIPMENT: ECG electrodes, small polyethylene catheters connected to statham pressure transducers (flushed by 2 automatic syringes at 4 ml/hr with heparinized saline), photography equipment, rotating drum.

RESULTS: In the orientation experiment, the labyrinthine-defective animal did not become disoriented during weightlessness, while the normal animal had orientation difficulty. There was a delay in retrieving the capsule, and the monkey died.

CONCLUSIONS: During zero-g, the normal animal failed to use his vision and touch sense to supplement missing balance cues.

PUBLICATIONS: 262, 374, 477

PRINCIPAL INVESTIGATOR(S): Richard E. Belleville

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Aerobee 150A

CLASSIFICATION: Animal - Rat

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To determine the gravity preference of a small animal when subjected to an artificial gravity field.

PROTOCOL: The white rats (2) were placed in a sounding rocket for approximately 8 minutes. They were placed in a cage where the animals could make a choice of gravity fields from .35 to 1.60 "g's" during approximately five minutes of zero-gravity trajectory.

EQUIPMENT: The animal environmental chambers were composed of two hinged tracks, deployed during flight to 15 degrees from vertical spin axis, associated instrumentation and environmental control equipment.

RESULTS: The rat spent the majority of the time in .8g.

CONCLUSIONS: Since the time of weightlessness and artificial gravity was limited, these results are not conclusive.

PUBLICATIONS: 29

PRINCIPAL INVESTIGATOR(S): Luclin S. Browning

EXPERIMENT TITLE/NUMBER: Genetic Effects of the Space Environment on the Reproductive Cells of Drosophila Adults and Pupae, P-1159

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal - Fruit fly (Drosophila melanogaster)

DISCIPLINE(S): Radiobiology, Genetics, Behavioral science

OBJECTIVES: To study possible transmissible genetic damage in the fruit fly caused by exposure to the conditions of spaceflight combined with continuous ionizing radiation.

PROTOCOL: Irradiated (<sup>85</sup>Sr: 1200-1500r) and nonirradiated female adults and larvae were compared with ground controls. Recessive lethal, visible mutations at specific loci, translocations, loss of dominant Y marker, cross-over in males, and nondisjunction were studied.

EQUIPMENT: Experiment package, <sup>85</sup>Sr source.

RESULTS: Increases in recessive lethal frequency in mature sperm, translocations and losses of dominant markers Y<sup>+</sup> and B from the Y chromosome in pupal stage were found in the irradiated flight specimens.

CONCLUSIONS: The changes could be attributed to vibration, acceleration, or contamination of the capsule atmosphere with formaldehyde, glutaraldehyde, and ethylene. Therefore, there is no evidence that weightlessness, acting either alone or in combination, can produce genetic effects, but neither can it be excluded as an interacting agent with other factors.

PUBLICATIONS: 96, 97, 98, 99, 100

PRINCIPAL INVESTIGATOR(S): Brenda Buckhold, John V. Slater, I. L. Silver,  
Tracy C. H. Yang, and C. A. Thomas

EXPERIMENT TITLE/NUMBER: Some Effects of Spaceflight on the Flour Beetle,  
Tribolium confusum, P-1039

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal - Flour beetle (Tribolium confusum)

DISCIPLINE(S): Radiobiology, Genetics, Behavioral science

OBJECTIVES: To study the effect of weightlessness and the combined effects of gamma radiation and weightlessness on somatic wing development, germ cells, and the pupal period in the flour beetle.

PROTOCOL: 720 Tribolium pupae between 19 and 27 hrs old were orbited, half in the presence of  $^{85}\text{Sr}$  and half shielded from it. Two-thirds of each pupae group had received a preradiation dose (1350r) of 180 keV  $\gamma$ -rays. Identical Earth controls were maintained. All were maintained at 85 F. Upon return, pupal period, wing abnormalities, and genetic damage was determined by mating experiment beetles with the controls.

EQUIPMENT: Three housing compartments, LiF disc dosimeters,  $^{85}\text{Sr}$  source.

RESULTS: Pupal period, wing abnormalities, and dominant lethality were significantly increased. "Split" mutation increased from ground values of 30% to 45%.

CONCLUSIONS: 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.

PUBLICATIONS: 101, 102, 103, 104, 105, 479, 480, 481, 546

PRINCIPAL INVESTIGATOR(S): Donald R. Ekberg, Elaine C. Silver, Judith L. Bushnag, and Edward W. Daniels

EXPERIMENT TITLE/NUMBER: Nuclear and Cellular Division in Pelomyxa carolinensis During Weightlessness, P-1035

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal - Amoeba (Pelomyxa carolinensis)

DISCIPLINE(S): Cell biology

OBJECTIVES: To study the effects of weightlessness on nuclear and cellular division in a single cell, using the giant multinucleate amoeba Pelomyxa carolinensis.

PROTOCOL: The amoebae were cultured and subcultured, placed in a buffer and fed paramecium. Five complete units of 24 chambers were assembled 2 days before launch. The organisms were loaded at F-18.5 hrs. The amoebae were screened and counted as they were selected for the chambers. After the amoebae and paramecium were loaded, the chambers were filled with THAM glycyl glycine buffer, with a small airspace left. The fixations were actuated 5 times inflight. At recovery, the organisms were counted, examined for mitotic forms, food vacuoles counted, and the gross morphology described.

EQUIPMENT: Experiment package with 24 chambers, each divided into three 5 ml compartments containing either amoebae, paramecium or fixative. The chambers were mounted on magnesium plates. Four of the chambers contained thermistors.

RESULTS: There were no significant differences in division rates between flight and control groups. There was a trend toward a higher division rate in well fed Pelomyxa during weightlessness. Nuclear division during weightlessness was synchronous, as in the controls. No difference was apparent in the postflight cell division rates of the flight group when compared to the controls.

CONCLUSIONS: Flight vibration and acceleration had no observable effect upon nuclear or cellular division of amoebae.

PUBLICATIONS: 182, 183

PRINCIPAL INVESTIGATOR(S): Jimmie L. Flume

EXPERIMENT TITLE/NUMBER: Effect of Space Flight on the in vitro Combining Capacity of Antigen and Antibody

PROGRAM/MISSION: Discoverer XVII

CLASSIFICATION: Human, Animal

DISCIPLINE(S): Cell biology, Hematology, Radiobiology

OBJECTIVES: To determine the specific reactivity between antigens and antibodies during spaceflight.

PROTOCOL: Samples of human gamma globulin and rabbit antiserum specific for human gamma globulin were dried on small squares of filter paper and mounted on both emulsion surfaces of nuclear track plates. The squares were immobilized by means of a thin Lucite plate and the entire package wrapped in black covering. On recovery, materials were eluted from the paper in saline, and reactivity was determined by means of passive hemagglutination.

EQUIPMENT: Millipore filter paper, nuclear emulsion tracking plates, black wrapping, thin Lucite plates, chemical dosimeters, alanine, albumin, silver phosphate glass rods, neutron sensitive film, antimony foil.

RESULTS: The only effect observed was an increase in reactivity in both antigen and antibody in the flight package.

CONCLUSIONS: The occurrence of greater reactivity is not understood, but it may be that sub-inhibitory concentrations of cosmic radiation may have a stimulatory effect on protein reactivity.

PUBLICATIONS: 198

PRINCIPAL INVESTIGATOR(S): Otto H. Gauer, and David Simmonds

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Blossom 3

CLASSIFICATION: Animal - Rhesus monkey (Macaca mulatta)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To test the physiological effects of rocket flight.

PROTOCOL: The monkey was kept at the Aero Medical Laboratory until flight time. At F-45 minutes, the monkey was given anesthesia, electrodes were implanted in its skin, and it was placed in the capsule. The capsule was mounted on the V-2 at F-30 min.

EQUIPMENT: V-2 nosecone redesigned as an animal capsule, electrodes, EKG, oxygen cylinder, audio amplifier.

RESULTS: The rocket reached a speed of 3,000 miles per hour. The parachute deployed, but did not open, with the monkey dying on impact. No information was recovered or telemetered.

CONCLUSIONS: This flight pointed out some of the problems of reliable instrumentation.

PUBLICATIONS: 374

PRINCIPAL INVESTIGATOR(S): Cloid D. Green

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Little Joe 3

CLASSIFICATION: Animal - Rhesus monkey (Macaca mulatta)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To observe the physiological effects of acceleration on a small primate and check the safety of the Project Mercury flight equipment, especially the launch abort system.

PROTOCOL: A performance test that involved tapping a telegraph key-like switch each time a red light flashed in the capsule was included.

EQUIPMENT: Rhesus monkey container (biopack).

RESULTS: The monkey was sent to an altitude of 84,000 m. The performance test was a success. There were no other findings of note.

CONCLUSIONS: This experiment verified the adequacy of flight equipment to be used in Project Mercury, and showed the biomedical effects of acceleration experienced during the abort of a Mercury flight after liftoff not to be adverse.

PUBLICATIONS: 351, 477

PRINCIPAL INVESTIGATOR(S): Clويد D. Green

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Little Joe 4

CLASSIFICATION: Animal - Rhesus monkey (Macaca mulatta)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To observe the physiological effects of acceleration on a small primate, particularly in the areas applying to the effects of the rapid onset of reverse acceleration during abort at maximum dynamic pressure.

PROTOCOL: A performance test that involved tapping a telegraph key-like switch each time a red light flashed in the capsule was included.

EQUIPMENT: Rhesus monkey container (biopack).

RESULTS: The monkey was sent to an altitude of 14,700 m. The performance test was a success. There were no other findings of note.

CONCLUSIONS: This experiment verified the adequacy of flight equipment to be used in Project Mercury and showed the biomedical effects of acceleration experienced during the abort of Mercury flight after liftoff not to be adverse.

PUBLICATIONS: 351, 477

PRINCIPAL INVESTIGATOR(S): Torquato Gualtierotti, F. Bracchi, and E. Rocca

EXPERIMENT TITLE/NUMBER: Orbiting Frog Otolith Experiment (OFO)

PROGRAM/MISSION: OFO

CLASSIFICATION: Animal - Bullfrog (Rana caelestiana)

DISCIPLINE(S): Neurosensory, Behavioral science

OBJECTIVES: To obtain information concerning the response of the basic acceleration sensor mechanism (hair cells of the otolith organ) to weightlessness.

PROTOCOL: 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. A centrifuge built into the experiment capsule subjected the sensors to a range of  $10^{-3}g$  during weightlessness and periodically up to 0.6g of stimulation.

EQUIPMENT: Neutral-buoyancy electrodes, ECG electrodes, Frog Otolith Equipment Package (consisting of spin motor, anti-vibration mounts, multipass gas exchanger, evaporator, thermostatic valve, water supply, oxygen reservoir, CO<sub>2</sub> absorber, amplifiers, and spacecraft data handling system).

RESULTS: During the first few days of weightlessness, the otolith showed 1) fluctuation of the activity at rest up to 20 times larger than on the ground, 2) a change of gain and mode of the responses to the centrifuge spin cycles; the mode changed from tonic to phasic and vice versa. The change 1) gradually disappeared in 4-5 days, the activity at rest returning to normal. The change 2) was maintained throughout the flight not showing trend to normalization.

CONCLUSIONS: Shows an indication of an only partial adaptation of a basic neural control process to weightlessness while some alteration remains. (Revealed partial adaptation process at the basic receptor level of living organisms to weightlessness).

PUBLICATIONS: 87, 231, 232, 233, 234, 235, 236, 237, 238

PRINCIPAL INVESTIGATOR(S): P. M. Hahn, Takashi Hoshizaki, and W. Ross Adey

EXPERIMENT TITLE/NUMBER: Circadian Rhythms of the Macaca nemestrina Monkey in Biosatellite III

PROGRAM/MISSION: Biosatellite III

CLASSIFICATION: Animal - Pig-tailed monkey (Macaca nemestrina)

DISCIPLINE(S): Chronobiology

OBJECTIVES: To study the effect of weightlessness on circadian rhythms.

PROTOCOL: Plotting techniques were used to estimate periodicity. 7.5 cycles for 24-hr. periods were used. Day averaging was the most common method used. Data obtained during the flight were interpolated to fixed 1.5 hour intervals.

EQUIPMENT: On-board flight recorder, camera, magnetic tape.

RESULTS:  $pCO_2$  (measurement of metabolism and respiration) had a periodicity of greater than 25 hours as did the subject's temperature and heart rate. The blood pressure rhythms were not larger than 24 hours. The 4 control animals had rhythms of 24 hours.

CONCLUSIONS: 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 synergistically to bring about its rapid deterioration. There was no evidence of this desynchronization in the ground controls. This leads to the possibility of the existence of a gravity dependent mechanism in the control of circadian rhythm.

PUBLICATIONS: 239, 285

PRINCIPAL INVESTIGATOR(S): J. Hanley, and W. Ross Adey

EXPERIMENT TITLE/NUMBER: Sleep and Wake States in the Biosatellite III  
Monkey: Visual and Computer Analysis of Telemetered  
Electroencephalographic Data from Earth Orbital  
Flight

PROGRAM/MISSION: Biosatellite III

CLASSIFICATION: Animal - Pig-tailed monkey (Macaca nemestrina)

DISCIPLINE(S): Chronobiology, Neurosensory

OBJECTIVES: To study the sleep and wake states in a complex mammalian system in a weightless environment.

PROTOCOL: Ten EEG, two EOG and two EMG channels were monitored. Data was telemetered to earth tracking stations at the rate of 22.4 kilobits/sec., and collected every 97 minutes. The monkey was acclimated to 12 hour day and 12 hour night cycle in the capsule.

EQUIPMENT: EEG, EOG and EMG, electrodes.

RESULTS: There were rapid transitions in state, brevity of state, and unusual transitions from one state to another. The monkey never achieved its normal terrestrial cycle. There was a dramatic reduction in REM and Stage 4 sleep. Eye movements, normally seen only in REM, were observed during State II and IV sleep. Eye movements decreased with increasing flight time, and ceased by orbit 126, accompanied by a change in EEG. None of the controls displayed this phenomenon.

CONCLUSIONS: The biological signals studied for correlates of the sleep and wake states of the primate were drastically affected by the weightless state. EEG, EOG, and EMG were all markedly disrupted by the zero gravity conditions. Moreover, the changes began concurrently with the onset of 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 8 attributable to fluid loss and redistribution of blood in the thorax consequent to the zero gravity state.

PUBLICATIONS: 6, 241

PRINCIPAL INVESTIGATOR(S): K. Hanning, and H. Wirth

EXPERIMENT TITLE/NUMBER: Electrophoresis Experiment, MA-C14

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human, Animal

DISCIPLINE(S): Cell biology

OBJECTIVES: To investigate and evaluate the increase in sample flow rate and sample resolution achievable in space.

PROTOCOL: The apparatus functioned automatically, requiring minimal crew intervention. Samples of rat bone marrow cells, spleen cells, lymph node cells with the addition of human erythrocytes as markers and a mixture of human and rabbit erythrocytes were studied. It was not necessary to collect the separated biomaterial fractions. An optoelectronic analysis of the separation was performed. A preparative separation was not used. A qualitative evaluation (by use of an optical system) was sufficient to determine the applicability of the method and to study the sharpness of separation.

EQUIPMENT: Separation chamber consisting of two cooling plates. Electrodes provided the electric field.

RESULTS: The experiment lasted for one Earth orbit. The optical system produced a light that was too bright to discern true cell distributions, but final analysis of scientific data by computer processing showed the expected distribution of separated cells.

CONCLUSIONS: The applicability of free-flow electrophoresis under zero-g conditions was confirmed. The technical problems arising from the special environmental conditions in a Spacelab can be controlled. It was demonstrated that the buffer flow systems operated despite the more difficult conditions imposed by a closed system. The effective removal of gases from the electrode buffer by the measures used was a necessary part of the experiment. The possibility of separating living cells under zero-g conditions was demonstrated. The cell aggregations that formed in the cell suspensions need not correspond to a decrease in viability.

PUBLICATIONS: 244, 245, 246, 247

PRINCIPAL INVESTIGATOR(S): Webb Haymaker, Bonne C. Look, and Eugene V. Benton

EXPERIMENT TITLE/NUMBER: Pocket Mouse Experiment (BIOCORE), M121

PROGRAM/MISSION: Apollo 17

CLASSIFICATION: Animal - Pocket Mouse (Perognathus longimembris)

DISCIPLINE(S): Radiobiology

OBJECTIVES: To determine whether a specific portion of the high Z-high energy (HZE) galactic cosmic ray particle spectrum, especially particles with Z no less than 6, can produce microscopically visible injury of brain, eye and other tissues.

PROTOCOL: Five pocket mice with plastic dosimeters implanted beneath the scalp underwent extensive ground testing for space flight environmental factors. Two cannisters were prepared of five mice each, one flight, one back-up to be used as a control, undergoing the same stresses as the flight mice. Upon return, the mice were sacrificed and fixed with FAM. The animals' heads were fixed and sliced into 1600 sections each, and compared with the heads of the sacrificed control mice (which had had paper dosimeters placed on their heads, and holes drilled to simulate the HZE particle paths that were encountered by the flight mice).

EQUIPMENT: Mouse flight cannister, life support system, dosimeters.

RESULTS: Four of the five flight mice returned alive; two in active and excellent condition; two docile and hunched up. The female was most subdued and uncoordinated on walking. Eighty cosmic ray particles were recorded in the five dosimeters which probably recorded 50% of the hits through the brain. 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 one. In the flight and back-up mice, there was hemorrhage in the middle ear cavity bilaterally (recovery condition directly related to the amount). There were 13 tiny lesions in the scalps of three flight mice. Five particles were recorded through the eyes. No retinal lesions were found. There were no pathological changes to the brain meninges or calvarium related to flight.

CONCLUSIONS: Although detailed studies were performed in an effort to answer the question whether HZE cosmic ray particles are injurious to brain and other tissue, it should be noted that the lack of demonstrable lesions does not negate this possibility. Substantially less shielded exposures to cosmic ray particles are needed if the effects (or lack of effects) of the particles on brain tissue and other target structures are to be established.

PUBLICATIONS: 20, 21, 138, 184, 250, 253, 254, 255, 256, 319, 349, 350, 355, 356, 411, 424, 425, 534, 575

PRINCIPAL INVESTIGATOR(S): James P. Henry

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Aerobee 3

CLASSIFICATION: Animal - Capuchin monkey (Cebus albifrons), mice

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To study the effects of weightlessness on both orientation and the physiology of the subject.

PROTOCOL: The two monkeys were seated, anesthetized, and one placed to receive +G<sub>z</sub> and the other placed to receive +G<sub>x</sub>. ECG was taken from both animals. Attempts were made to measure arterial and venous pressures. Two mice, one normal and one labyrinthectomized, were placed in a rotating drum (4 rpm) and photographed.

EQUIPMENT: Rotating mouse drum (with special shelf on one side), camera.

RESULTS: Both monkeys and mice survived the flight without demonstrable ill effects. The measurements of arterial and venous pressures failed. The labyrinthine-defective mouse did well, if given a foothold in the rotating drum while the normal mouse clawed the air trying to get his balance.

CONCLUSIONS: These were the first living creatures to survive spaceflight conditions. Minimum uncoordination and disorientation is experienced as long as the subject retains tactile and has visual references.

PUBLICATIONS: 259, 261, 262, 374, 477

PRINCIPAL INVESTIGATOR(S): James P. Henry

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Blossom 5

CLASSIFICATION: Animal - Cynomolgus monkey (Macaca irus)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To study acceleration effects on a monkey.

PROTOCOL: The monkey was kept at the Aero Medical Laboratory until flight time. At 45 minutes before flight, the monkey was given anesthesia, electrodes set in its skin, and placed in the capsule. The capsule was placed on the V-2 rocket at 30 minutes before flight.

EQUIPMENT: Telemetry devices for heart beat and respiration, V-2 nosecone redesigned as an animal capsule, electrodes, EKG, oxygen cylinder, audio amplifier.

RESULTS: The rocket reached a speed of 3,000 miles per hour. The parachute deployed, but did not open, with the monkey dying on impact. Some information was telemetered, showing normal respiration and heart rate.

CONCLUSIONS: Space flight seemed to have no adverse effect on the physiology of the monkey.

PUBLICATIONS: 259, 261, 262, 374

PRINCIPAL INVESTIGATOR(S): James P. Henry

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Blossom 6

CLASSIFICATION: Animal - Cynomolgus monkey (Macaca irus)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To study the effects of rocket flight on a living subject.

PROCEDURE: The monkey was kept at the Aero Medical Laboratory until flight time. At 45 minutes before flight, the monkey was given anesthesia, electrodes implanted in its skin, and placed in the capsule. The capsule was mounted on the V-2 rocket at 30 minutes before flight.

EQUIPMENT: Telemetry devices for heart beat and respiration, V-2 nosecone redesigned as an animal capsule, electrodes, EKG, oxygen cylinder, audio amplifier.

RESULTS: The rocket reached a speed of 3,000 miles per hour. The parachute deployed, but did not open, with the monkey dying on impact. Some information was telemetered, showing normal respiration and heart rate.

CONCLUSIONS: Space flight seemed to have no adverse effect on the physiology of the monkey.

PUBLICATIONS: 259, 261, 262, 374

PRINCIPAL INVESTIGATOR(S): James P. Henry

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Blossom 7

CLASSIFICATION: Animal - Mouse

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To study the effects of zero gravity on animal behavior.

PROTOCOL: The mouse was placed in the clear container unanesthetized, and photographed at short intervals of 1 second duration at 4 second intervals.

EQUIPMENT: Photographic equipment, pie-wedge-shaped mouse chamber of Plexiglass, an accelerometer.

RESULTS: The parachute deployed, but failed to open and the mouse was killed on impact, but the film was recovered. The pictures showed the mouse floating around, with tactile and visual senses allowing orientation during a brief period of weightlessness.

CONCLUSIONS: This experiment contradicted the popular theory that zero-g would cause disorientation.

PUBLICATIONS: 259, 261, 262, 374

PRINCIPAL INVESTIGATOR(S): James P. Henry

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Mercury 2 (MR2)

CLASSIFICATION: Animal - Chimpanzee (Pan troglodytes)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To determine the safety of the Mercury spacecraft for suborbital manned flight.

PROTOCOL: The chimp, "Ham" was trained for 219 hrs. over a 15 mo. period, and was successfully launched and recovered. Two psychomotor tasks were conducted in flight. After recovery, the chimp was examined for physiological abnormalities.

EQUIPMENT: ECG electrodes of stainless steel wires threaded subcutaneously, pneumograph, rectal thermistor, chimp couch system, photographic equipment.

RESULTS: Pulse, respiration, and blood pressure were normal. Performance of tests was unaffected by weightlessness. The chimp reached a speed of 5,800 mph and an altitude of 156 mi. over a range of 414 mi.

CONCLUSIONS: This experiment demonstrated the validity of Mercury spacecraft. Weightlessness left visual and tactile references unimpaired and showed that physical and mental demands were not excessive.

PUBLICATIONS: 88, 261, 264, 351, 452, 477, 559

PRINCIPAL INVESTIGATOR(S): James P. Henry

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Mercury 5 (MA-5)

CLASSIFICATION: Animal - Chimpanzee (Pan troglodytes)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To evaluate the safety of the Mercury spacecraft for manned orbital flight and determine the physiological effects of weightlessness.

PROTOCOL: The chimp, "Enos" was trained for 1263 hrs. during a 16-mo. period, and was successfully launched in a Mercury capsule and recovered. Data from flight (which was not telemetered) was then analyzed.

EQUIPMENT: ECG electrodes of stainless steel wires threaded subcutaneously, pneumograph, rectal thermistor, psychomotor testing equipment, Foley catheter (to collect urine), intravascular catheters (for arterial and venous pressures recorded inflight but not telemetered), 0-g food and water dispensers, chimp couch system, and photography equipment.

RESULTS: Blood pressure was high and cardiac rhythms were irregular because of an instrumentation problem. The chimpanzee successfully performed complex multiple operant tasks and returned in good physiological condition.

CONCLUSIONS: This experiment demonstrated the validity of the capsule environment control system for subsequent use with man. It showed that the vehicles could be successfully recovered, and that short-term weightlessness had no adverse physiological effects.

PUBLICATIONS: 89, 262, 264, 351, 388, 451, 477, 558

PRINCIPAL INVESTIGATOR(S): John E. Hewitt

EXPERIMENT TITLE/NUMBER: Radiation Exposures During the Biosatellite II  
Flight

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal, Plant, Microorganism

DISCIPLINE(S): Radiobiology

OBJECTIVES: To determine the combined effects of radiation and weightlessness on lethality and mutagenesis in a variety of living systems.

PROTOCOL: The biologic material from each experiment was divided into four groups; flight groups irradiated, and non-irradiated, and Earth control groups irradiated and non-irradiated.  $^{85}\text{Sr}$  was used as the radiation source and Lithium fluoride (LiF) thermoluminescent powder was selected as the primary dosimeter. The packages were placed in the capsule at different distances from the source so that each would receive its correct exposure.

EQUIPMENT: Capsule, experiment packages, nuclear emulsion package, backscatter shield, heat shield, source holder,  $^{85}\text{Sr}$  source, LiF powder dosimeters,  $\text{CaF}_2$  dosimeters.

RESULTS: The radiation exposures in the control areas were quite low. Few were above 0.5 R. From nuclear emulsion measurements, an upper limit dose due to protons was 40 mB for the mission. There were 10.1 traversals of atomic nuclei of  $Z \geq 20/\text{cm}^2$  during the mission.

CONCLUSIONS: Nuclear emulsions measurements verified that radiation doses due to space radiations are very low in orbits similar to that of Biosatellite II. It is highly unlikely that any difference found between the biologic responses of the same experiment in the flight and Earth control capsules could be attributed to radiation exposure differences, nor could any unusual results be attributed to the presence in the capsules of a large component of low-energy radiation produced by multiple scattering.

PUBLICATIONS: 268

PRINCIPAL INVESTIGATOR(S): Takashi Hoshizaki, Ross Durham, and W. Ross Adey

EXPERIMENT TITLE/NUMBER: Sleep/Wake Activity Patterns of a Macaca nemestrina Monkey During Nine Days of Weightlessness

PROGRAM/MISSION: Biosatellite III

CLASSIFICATION: Animal - Pig-tailed monkey (Macaca nemestrina)

DISCIPLINE(S): Chronobiology

OBJECTIVES: To study the possible effects of space environment on the sleep/awake cycle of a pig-tailed monkey.

PROTOCOL: Time-lapse photographic records of the flight and control animals were taken in conjunction with other physiological data. Pictures were taken every 20 minutes. The pictures were analysed for the cycle with the status of the eyes, i.e. closed, open, not discernible.

EQUIPMENT: 16mm movie cameras, 24 hour clocks.

RESULTS: The subject was entrained to 24 hour cycle but with a shift of 2 hours sleep 1400-0200 CT, wake 0200 to 1400 CT. With the exception of the last two days, the subject tended to remain on a consistent schedule regarding onset of "night" sleep. He remained asleep for longer periods of time as the flight progressed. Wakefulness apparently never increased in the "night" mode, but increased during "day" mode on days 7, 8, and 9.

CONCLUSIONS: "Bonny" changed rapidly back and forth from the sleep to wake status. From the findings on a 24-hour rhythm in blood pressure, a 26-hour rhythm in the heart rate, body and brain temperature and pCO<sub>2</sub>, and the 24-hr. rhythm in the sleep/wake activity, it is concluded that internal desynchronization occurred in the flight subject. Desynchronization may have contributed to the physiological pathology that prompted the termination of the flight. Such a desynchronization was not observed in control subjects.

PUBLICATIONS: 2, 4, 6, 7, 241, 285

PRINCIPAL INVESTIGATOR(S): Allan A. Katzberg

EXPERIMENT TITLE/NUMBER: The Effects of Space Flight on Living Human Cells  
Aboard the Discoverer Vehicle

PROGRAM/MISSION: Discoverer XVIII

CLASSIFICATION: Animal - Chicken embryo tissue

DISCIPLINE(S): Cell biology, Behavioral science

OBJECTIVES: To study traumatic effects of space flight, using cell cultures, since cells are very sensitive to alterations in environment. The effect can be morphological or physiological, and may be permanent, temporary, or lethal.

PROTOCOL: A population of 50,000 cells was suspended in 3cc medium and sealed in glass ampules which also contained a small glass coverslip. These cells were astrocytic and oligodendroglial derivatives cultured from the corpus callosum of the brain of a 10-day-old chick embryo.

EQUIPMENT: Glass ampules, salt solution, 10% horse serum, refrigeration units, neutron film pack, chem cal dosimeters, gold foil, glass needle sets, 552 film strips, polyethylene foam (for packing), alanine packets, 1 step plate and film (in all three planes), nuclear track plates.

RESULTS: The culture was in good condition on the 12th day following preparation, with a high level of viability. There was some inhibition of growth initiation, but it was insignificant. Postflight, the cells showed no significant biochemical, cytological, or genetic changes.

CONCLUSIONS: Not conclusive, due to the less than ideal flight conditions.

PUBLICATIONS: 305, 306, 307, 308

PRINCIPAL INVESTIGATOR(S): Pauline B. Mack

EXPERIMENT TITLE/NUMBER: Bone Density Changes in a Macaca nemestrina Monkey  
During the Biosatellite III Project

PROGRAM/MISSION: Biosatellite III

CLASSIFICATION: Animal - Pig-tailed monkey (Macaca nemestrina)

DISCIPLINE(S): Musculoskeletal

OBJECTIVES: To find changes in bone density during weightlessness by the x-ray radiographic method.

PROTOCOL: Preflight, several series of bone radiographs were taken 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. Postflight radiographs were taken after recovery.

EQUIPMENT: Bone densitometer, digital-analog computer.

RESULTS: Postflight bone density losses at the sites analyzed ranged from -1.71 to -17.52% compared to -0.12 to -10.72% for ground controls.

CONCLUSIONS: Immobilization of flight has been found definitely to be associated with decrease in skeletal density in human subjects in prior studies. The bone density losses in the flight animal were considered to be due to immobilization coupled with the aggregate stresses of the flight environment.

PUBLICATIONS: 369

PRINCIPAL INVESTIGATOR(S): P. J. Maher, and James P. Henry

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Aerobee 1

CLASSIFICATION: Animal - Capuchin monkey (Cebus albifrons)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To observe some physiological effects of space flight.

PROTOCOL: EKG and respiration measured. The monkey was anesthetized.

EQUIPMENT: EKG electrodes.

RESULTS: Animal not recovered due to parachute failure.

CONCLUSIONS: Inconclusive.

PUBLICATIONS: 259, 262, 374, 477

PRINCIPAL INVESTIGATOR(S): P. J. Maher, and Otto H. Gauer

EXPERIMENT TITLE/NUMBER:

PROGRAM/MISSION: Blossom 4

CLASSIFICATION: Animal - Rhesus monkey (Macaca mulatta)

DISCIPLINE(S): Behavioral science, Environmental health

OBJECTIVES: To study acceleration effects on a monkey.

PROTOCOL: The monkey was kept at the Aero Medical Laboratory until flight time. At 45 minutes before flight, the monkey was given anesthesia, electrodes set in its skin, and placed in the capsule. The capsule was placed on the V-2 rocket at 30 minutes before flight.

EQUIPMENT: Telemetry devices for heart beat and respiration, V-2 nosecone redesigned as an animal capsule, electrodes, EKG, oxygen cylinder, audio amplifier.

RESULTS: The rocket reached a speed of 3,000 miles per hour. The parachute deployed, but did not open, with the monkey dying on impact. Some information was telemetered, showing normal respiration and heart rate.

CONCLUSIONS: It was not known if space flight injured the animal or not.

PUBLICATIONS: 374, 477

PRINCIPAL INVESTIGATOR(S): John P. Meehan, and Roland D. Rader

EXPERIMENT TITLE/NUMBER: Cardiovascular Observations of the Macaca nemestrina Monkey in Biosatellite III

PROGRAM/MISSION: Biosatellite III

CLASSIFICATION: Animal - Pig-tailed monkey (Macaca nemestrina)

DISCIPLINE(S): Cardiovascular

OBJECTIVES: To determine the physiological effects of Earth orbit on nonhuman primates, to provide insights into possible hazards associated with long-term space flights, and to acquire information on basic physiological adjustments to extended weightlessness, particularly concerning the cardiovascular system.

PROTOCOL: Inflight vascular pressures were obtained by catheterization techniques and recorded without amplification on an orbital galvanometric oscillograph. One pair of electrodes provided electrocardiographic and respiratory information. Four indwelling catheters, two venous and two arterial, yielded redundant pressure measurements. Heparin pumps were used to keep the catheters clear. There were four ground control monkeys, plus baseline data from the flight monkey for comparative analysis.

EQUIPMENT: Catheters, orbital galvanometric oscillograph, ECG electrodes.

RESULTS: The flight subject experienced an immediate sustained increase in central venous pressure resulting from a central pooling of blood volume. This shift in blood volume is thought to have initiated the Gauer-Henry mechanism whereby urine volume was initially maintained at a high level. This coupled with a high evaporative fluid loss, produced an early dehydration probably associated with electrolyte imbalance. Venous pressure started to fall on Day 5, while arterial pressure and heart rate were within physiological limits until Day 8, i.e., near the termination of the flight.

CONCLUSIONS: There was a shift of blood volume toward the heart. The observed increase in atrial pressure of 2-3 cm H<sub>2</sub>O was large enough to provide a stimulus for the loss of body fluid described by Gauer and Henry. Weightlessness and hypothermia acted to shift blood volume centrally. This 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. There were a number of factors all acting in concert which may have prevented the effective adaptation of the monkey to the environment.

PUBLICATIONS: 2, 3, 4, 7, 387, 389, 390, 391, 392, 556

PRINCIPAL INVESTIGATOR(S): Judith Miles

EXPERIMENT TITLE/NUMBER: Web Formation, ED52

PROGRAM/MISSION: Skylab 3

CLASSIFICATION: Animal - Cross spider (Araneous diadematus)

DISCIPLINE(S): Behavioral science, Neurosensory

OBJECTIVES: To compare the detailed structure of webs built by spiders in null gravity with those built in a one-g environment to determine how weightlessness affects the central nervous system.

PROTOCOL: The crewmen deployed the spider cage and an automatic 16-mm photography system, released the spider in the cage, took 35-mm photographs, and obtained television coverage of the spiders and webs.

EQUIPMENT: Spider cage, photographic equipment.

RESULTS: Returned web samples showed finer threads were used in flight than in ground-built webs. Anita's death was reported on the 51st day of the mission and Arabella's death was discovered on return to earth. Both spiders apparently died of dehydration and are preserved at the Smithsonian Institute.

CONCLUSIONS: There is positive evidence that the spider utilized a gravity-sensing organ to size her thread.

PUBLICATIONS: 197, 377, 500

PRINCIPAL INVESTIGATOR(S): Irwin I. Oster

EXPERIMENT TITLE/NUMBER: Genetic Implications of Space Flight, P-1160

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal - Fruit fly (Drosophila melanogaster)

DISCIPLINE(S): Radiobiology, Genetics, Behavioral science

OBJECTIVES: To determine to what extent weightlessness may affect the responses of somatic cells to ionizing gamma radiation, using immature stages (instar pupal stages) of Drosophila melanogaster.

PROTOCOL: Eggs were collected using the Sonnenblick method. Sixty 1st instar larvae placed in each module (the package had 8 modules). Ten 1st instar larvae w/ring chromosomes were selected for cytologic preparations. Additional larvae were added to bring count to 290. After the 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 1200 to 1500r of <sup>90</sup>Sr. One unit was shielded. A similar configuration was used on an Earth-based control. Three additional controls were maintained. Optimum conditions of humidity, temperature, and food were maintained.

EQUIPMENT: Drosophila flight package consisting of eight larvae modules equipped with dosimeters and thermistors, an <sup>90</sup>Sr source, and LiF radiation detectors.

RESULTS: Higher mortality of orbited larvae than Earth radiation-exposed larvae was noted with no detectable effect on developmental time. Chromosomes flown and irradiated showed a statistically significant increase in chromosome change over Earth controls. The nonirradiated flown material did not appear different from the Earth control. Flight and flight irradiated chromosomes showed evidence of chromosome nondisjunctions.

CONCLUSIONS: Radiation interacts with weightlessness to induce more premature aging and chromosome damage in actively growing and metabolizing specimens than in those irradiated at Earth level. Possibly some factor, more than likely weightlessness, is capable of causing improper chromosome replication and the formation of chromosome translations.

PUBLICATIONS: 414, 415, 416, 417

PRINCIPAL INVESTIGATOR(S): Walter Ruether, E. H. Graul, H. Planel, J. P. Coleilhavoup, Horst Buecker, R. Kaiser, J. P. Massue, R. Pfohl, W. Enge, O. C. Allkofer, K. Bartholomae, R. Beaujean, W. Heinrich, K. Fukui, Eugene V. Benton, E. Schopper, G. Henig, J. U. Schott, H. Francois, and G. Portal

EXPERIMENT TITLE/NUMBER: BIOSTACK I, II

PROGRAM/MISSION: Apollo 16, 17

CLASSIFICATION: Animal - Brine shrimp eggs (*Artemia salina*)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To study the biological effects of individual heavy nuclei with high energy loss (HZE), to obtain as much information as possible on the mechanisms of biological damage by HZE particles, to measure the charge and energy spectra of cosmic radiation within the Apollo Command Module, and to provide data to allow an estimate of the hazard to man from space radiation.

PROTOCOL: Bacterial spores, protozoan cysts, plant seeds, shrimp eggs and insect eggs were studied for inhibition of germination, inhibition of cell growth, inhibition of organ development, developmental anomalies in various stages of growth, and mutation induction using several physical radiation detectors. The BIOSTACK unit was flown in the Command Module where shielding to ambient cosmic radiation was minimal. After the flight, the ground controls and the flight package were disassembled and particle hits were graphed.

EQUIPMENT: Hermetically sealed aluminum container, containing a series of select biologic material each sandwiched between several types of dosimeters (n. clear emulsions, cellulose nitrate, polycarbonate, LiF), and thermistors.

RESULTS: The shrimp eggs were extremely sensitive to HZE. 10% of flight HZE hit eggs developed to swimming larvae. Larvae had high mortality, few reached maturity, none were normal in growth and behavior. Time to deposit of eggs after mating doubled. F1 progeny were reduced in number and malformations increased 10-fold.

CONCLUSIONS: The data confirms the assumption that HZE particle-induced damage might become manifest if a significant number of nonreplaceable cells are destroyed.

PUBLICATIONS: 28, 113, 114, 115, 116, 117, 118, 119, 120, 185, 186, 213, 257, 258, 420, 430, 454

PRINCIPAL INVESTIGATOR(S): Walter Ruether, Horst Buecker, R. Kaiser, J. P. Massue, R. Pfonl, W. Enge, O. C. Ailkofer, K. Bartholomae, R. Beaujean, W. Heinrich, K. Fukui, Eugene V. Benton, E. Schopper, G. Henig, J. U. Schott, H. Francois, and G. Portal

EXPERIMENT TITLE/NUMBER: BIOSTACK II

PROGRAM/MISSION: Apollo 17

CLASSIFICATION: Animal - Grasshopper eggs (Carausius morosus)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To study, in a direct manner, the biological effects of individual heavy nuclei with high energy loss (HZE), to obtain as much information as possible on the mechanisms of biological damage by HZE particles, to measure the charge and energy spectra of cosmic radiation within the Apollo Command Module, and to provide data to allow an estimate of the hazard to man from space radiation.

PROTOCOL: Bacterial spores, protozoan cysts, plant seeds, shrimp eggs and insect eggs were studied for inhibition of germination, inhibition of cell growth, inhibition of organ development, developmental anomalies in various stages of growth and mutation induction using several physical radiation detectors. The BIOSTACK unit was flown in the Command Module where shielding to ambient cosmic radiation was minimal. After the flight, the ground controls and the flight package were disassembled and particle hits were graphed.

EQUIPMENT: Hermetically sealed aluminum container, containing a series of select biologic material, each sandwiched between several types of dosimeters (nuclear emulsions, cellulose nitrate, polycarbonate, LiF), and thermistors.

RESULTS: The grasshopper eggs were sensitive to HZE. Hatching of HZE hit eggs was reduced and mortality increased. Malformations (fused segments, short legs) increased from control 1.5% to 23%.

CONCLUSIONS: The experiment confirms the assumption that HZE particle-induced damage might become manifest if a significant number of nonreplaceable cells are destroyed.

PUBLICATIONS: 113, 115, 116, 117, 119, 120, 213

PRINCIPAL INVESTIGATOR(S): Walter Ruether, Horst Buecker, R. Kaiser, J. P. Massue, R. Pfohl, W. Enge, O. C. Allkofer, K. Bartholomae, R. Beaujean, W. Heinrich, K. Fukui, Eugene V. Benton, E. Schopper, G. Henig, J. U. Schott, H. Francois, and G. Portal

EXPERIMENT TITLE/NUMBER: BIOSTACK II

PROGRAM/MISSION: Apollo 17

CLASSIFICATION: Animal - Flour beetle eggs (Tribelium confusum)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To study the biological effects of individual heavy nuclei with high energy loss (HZE), to obtain as much information as possible on the mechanisms of biological damage by HZE particles, to measure the charge and energy spectra of cosmic radiation within the Apollo Command Module, and to provide data to allow an estimate of the hazard to man from space radiation.

PROTOCOL: Bacterial spores, protozoan cysts, plant seeds, shrimp eggs and insect eggs were studied for inhibition of germination, inhibition of cell growth, inhibition of organ development, developmental anomalies in various stages of growth, and mutation induction using several physical radiation detectors. The BIOSTACK unit was flown in the Command Module where shielding to ambient cosmic radiation was minimal. After the flight, the ground controls and the flight package were disassembled and particle hits were graphed.

EQUIPMENT: Hermetically sealed aluminum container, containing a series of select biologic material each sandwiched between several types of dosimeters (nuclear emulsions, cellulose nitrate, polycarbonate, LiF), and thermistors.

RESULTS: The flour beetle eggs were extremely sensitive to HZE. Hatching frequency was significantly reduced with high mortality after hatching. Abnormalities (curved abdomen, fused segments, split or shortened elytra) increased from control 2.5% to 48%.

CONCLUSIONS: The data confirms the assumption that HZE particle-induced damage might become manifest if a significant number of nonreplaceable cells are destroyed.

PUBLICATIONS: 113, 115, 116, 117, 119, 120, 213

**PRINCIPAL INVESTIGATOR(S):** Walter Ruether, E. H. Graul, W. Heinrich, H. Planel, Horst Buecker, M. Delpoux, S. Fogel, M. Freeling, G. Horneck, A. R. Kranz, U. Scheidemann, C. Thomas, C. A. Tobias, B. Toth, T. Yang, O. C. Allkofer, R. Beaujean, E. V. Benton, W. Enge, R. Facius, H. Francois, D. Hildebrand, C. Jacquot, R. Kaiser, J. P. Massue, E. Obst, D. D. Peterson, R. Pfohl, G. Portal, G. Reitz, E. Schopper, M. Schaefer, J. U. Schott, and G. Siegmon

**EXPERIMENT TITLE/NUMBER:** BIOSTACK III

**PROGRAM/MISSION:** Apollo-Soyuz Test Project

**CLASSIFICATION:** Animal - Brine shrimp eggs, (Artemia salina), Flour beetle eggs (Tribolium confusum), Grasshopper eggs (Carausius morosus)

**DISCIPLINE(S):** Radiobiology, Cell biology, Behavioral science

**OBJECTIVES:** To study the influence of HZE particles on development, morphogenesis, and histology.

**PROTOCOL:** The BIOSTACK flight experiment was stored in the R-1 compartment in the Apollo capsule where there was the least shielding from ambient radiation. The specimens were arranged in monolayers and imbedded in polyvinyl alcohol (PVA), and stacked between track detector sheets so particle tracks could be located in relation to biological objects and the physical quantities of these particles could be determined.

**EQUIPMENT:** The biological specimens were imbedded in PVA. There were 2 cylindrical aluminum containers which enclosed a stack of biological specimens and dosimeters. K2 nuclear emulsion plates were used as dosimeters for these specimens.

**RESULTS:** The total dose average was 1.21 mJ/Kg and the dose rate average was 5.04 J/kg-h. For particles  $Z = 1$ ,  $Z = 2$ , the total dose was 0.014 mJ/Kg;  $Z > 2$  total dose was 0.015 mJ/Kg. Protons of energies  $< 28$  MeV, alpha particles of energies  $< 200$  MeV/nucleon and particles of  $Z \geq 4$  at all energies were detected. Most of the animal eggs hit by an HZE particle showed serious damage during development. In Artemia salina eggs, the hatching rate was significantly reduced and development anomalies were frequently observed. Histological studies on anomalous larvae showed cellular and tissue damage primarily at the extremities and the abdomen.

**CONCLUSIONS:** These changes may be due to the differentiated dynamics of the developmental processes of the egg. The observations generally confirmed the results of the previous BIOSTACK experiments. HZE-particle-induced damage might become manifest if nonreplaceable cells are destroyed. In manned space flight, the primary concern would be the nervous system. However, the risk to man from HZE particle during space flight can be sufficiently lowered if the maximum possible shielding against HZE particle bombardment is ensured in the design and construction of future space vehicles.

**PUBLICATIONS:** 121, 122, 212

PRINCIPAL INVESTIGATOR(S): Herbert W. Scheld, Anwar A. Baky, John F. Boyd, Victor B. Eichler, P. M. Fuller, Ronald B. Hoffman, J. R. Keefe, K. P. Kuchnow, J. M. Oppenheimer, Gloria A. Salinas, and R. J. von Baumgarten

EXPERIMENT TITLE/NUMBER: Killifish Hatching and Orientation, MA-161

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Animal - Killifish (Fundulus heteroclitus)

DISCIPLINE(S): Cell biology, Behavioral science, Neurosensory

OBJECTIVES: To evaluate the hazards inherent in the exposure of living organisms to the space environment during critical portions of the life cycles or for extended periods. The points of primary emphasis were the function and development of the vestibular system and calcium deposition, particularly as it relates to otolith development.

PROTOCOL: The experiment package consisted of two parts: A series of staged embryos in five individual compartments of a polyethylene bag and a series of preconditioned juvenile fish in a similar bag. Embryos at 32, 66, 128, 216, and 336 hours were used. Development occurred at a constant temperature of 295-K. Experiment packages were mounted on the Docking Module wall and photographed periodically during the mission. At splashdown, vestibular sensitivity was tested in a rotating, striped drum. Subsequently, additional vestibular orientation tests were performed. Some of the killifish were fixed for microscopic examination.

EQUIPMENT: Transport control package, experimental package, rotating striped drum, photography equipment.

RESULTS: Postflight tests with rotating striped drum, light orientation, geotaxis, parabolic trajectory on fry, hatchlings, mature (R+0.5 yr) were not significantly different. Inflight visual conditioning was not significant. Juvenile fish exhibited looping swimming activity. Hatchlings from 336 hr egg stage also looped. Normal vestibular behavior was suggested by MD-9. No growth abnormalities were observed in embryos that developed inflight. Normal diving response resumed by R+0. Juvenile swimming patterns indicated abnormal swim bladders.

CONCLUSIONS: There appeared to be no significant effect of space flight on vestibular senses and embryonic development.

PUBLICATIONS: 470, 471

PRINCIPAL INVESTIGATOR(S): Gerald R. Taylor, R. A. Long, and Walter L. Ellis

EXPERIMENT TITLE/NUMBER: Microbial Response to Space Environment

PROGRAM/MISSION: Apollo 16

CLASSIFICATION: Animal - Nematode larvae (Nematospiroides dubius)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To evaluate the effect of a particular space flight on the survival rate of different species.

PROTOCOL: Each microbial sample containing 100 to 1 million live cells, was housed in chambers or cuvettes for flight and ground controls. Microbes could be suspended in 50 $\mu$ l of fluid or dried on a carrier, and exposed to vacuum of space or retained at 1 atm. An optical filtering system controlled the total radiant energy reaching exposed test systems from a minimum of  $4 \times 10^4$  ergs/cm<sup>2</sup> to a maximum of  $8 \times 10^8$  ergs/cm<sup>2</sup>.

EQUIPMENT: Microbial ecology evaluation device (MEED) containing 798 cuvettes, 140 neutral density filters, 28 bandpass filters, 8 recording thermometers, one high-energy multicharged particle dosimeter, 54 potassium ferrioxalate actinometry cuvettes, 44 photographic film cuvettes, and 18 thermoluminescent dosimeter cuvettes.

RESULTS: Solar ultraviolet irradiation at 254 nm ( $2 \times 10^5$  ergs/cm<sup>2</sup>) inhibited growth to mature worms, and postflight infection of murine host. Nonirradiated larvae showed no change in survival rate, infectivity, development to adults or their egg production. The egg viability was significantly decreased.

CONCLUSIONS: No statistically valid differences could be detected in the survival of flight samples when compared to corresponding ground-based controls.

PUBLICATIONS: 354, 503, 504, 505, 513, 514, 515

PRINCIPAL INVESTIGATOR(S): R. J. von Baumgarten, Richard C. Simmonds, John F. Boyd, and Owen K. Garriott

EXPERIMENT TITLE/NUMBER: Effects of Prolonged Weightlessness on the Swimming Pattern of Fish Aboard Skylab 3, SD10

PROGRAM/MISSION: Skylab 3

CLASSIFICATION: Animal - Killifish (Fundulus heteroclitus)

DISCIPLINE(S): Behavioral science, Neurosensory

OBJECTIVES: To determine whether the vestibular behavior of fish would show any disturbance during the first few days in space, whether the peculiar "looping behavior" of fish observed during parabolic flight would continue during prolonged spaceflight, and whether fish embryos would develop, hatch, and swim normally in weightlessness.

PROTOCOL: Two sighted fingerling fish and 50 embryonated fish eggs were flown in a polyethylene "aquarium." The bag containing the fish and eggs was sealed in a tin can at 1 atm pressure. A duplicate bag of fish and eggs served as a ground control. Inflight, the can was opened and the bag taped to a wall for observation with pictures being taken on days 3 and 21. The eggs were fertilized at F-96 hrs.

EQUIPMENT: Polyethylene bag, transport canister, photographic equipment

RESULTS: The two fingerlings swam in tight circles inflight, looping sideways most of the time, with their backs directed towards the light source. The frequency of the looping episodes diminished slowly after the third day until normal swimming was prevalent. Development of embryonic stages (32, 66, 128, 216, 336h) continued inflight. Microscopy of fry and hatchling showed CNS, cardiovascular, optic, vestibular systems normal. Juvenile swimming pattern postflight suggested abnormal swim bladders.

CONCLUSIONS: Weightlessness acts as a permanent vestibular stimulus until long-term habituation occurs. This appears to be the result of a central active inhibitory process and not of fatigue or receptor adaptation alone. The swimming anomaly could be due to (1) absence of continuous bending of sense hairs to a certain extent by gravity, causing the fish to tilt forward in an attempt to increase leverage on the hairs; or (2) an attempt by the fish to create a gravitoinertial stimulus by "centrifuging" its otoliths by looping.

PUBLICATIONS: 471, 544

PRINCIPAL INVESTIGATOR(S): R. C. von Borstel, R. H. Smith, Anna R. Whiting,  
and D. S. Grosch

EXPERIMENT TITLE/NUMBER: Mutational and Physiologic Responses of Habrobracon  
in Biosatellite II, P-1079

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal, Microorganism - Parasitic wasp (Habrobracon  
juglandis), Brine shrimp cysts (Artemia salina),  
Microorganism (Saccharomyces cerevisiae)

DISCIPLINE(S): Radiobiology, Genetics, Behavioral science

OBJECTIVES: To survey mature sperm and all different 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.

PROTOCOL: Male and female wasps were irradiated preflight, inflight, or not  
at all with <sup>85</sup>Sr at 4000 R, 2000 R, 1000 R, 500 R or 0 R. Thirty parameters  
of genetic, mutational, biochemical, behavioral, and physiological character  
were measured. Artemia salina cysts were used since they are sensitive to  
vibration. Saccharomyces cerevisiae were used to detect scattered radiation.

EQUIPMENT: Habrobracon flight containers, <sup>85</sup>Sr source, LiF powder, glass rod  
dosimeters.

RESULTS: Spaceflight effects were enhancement of fecundity and hatchability  
of primitive and transitional oogonia, disorientation of male mating behavior,  
increased life span of females and decreased xanthine dehydrogenase activity  
in males. The effects of radiation were decreased hatchability and enhanced  
fecundity of eggs. The only mutagenic effect found was a threefold  
enhancement of the recessive lethal mutation frequency in the nonirradiated  
sperm in the orbited males. No difference was found in intragenic or  
intergenic recombination endpoints comparing flight and ground control  
Saccharomyces. The Artemia cysts were not influenced by spaceflight or gamma  
radiation received inflight.

CONCLUSIONS: The enhancement of spontaneous recessive lethal frequency in  
sperm was induced by some factor of the flight profile other than  
weightlessness. The excess of deaths found among the offspring from females  
flown might have been from a mixture of chromosome imbalance phenomena and  
recessive lethal mutations induced by the spaceflight conditions. The  
increased fertilizing capacity appeared to be an enhancing effect of radiation  
combined with weightlessness. The strong trend for enhanced emergence from  
Artemia cysts might have been caused by vibration.

PUBLICATIONS: 226, 227, 228, 229, 230, 545, 546, 547, 548, 549

PRINCIPAL INVESTIGATOR(S): D. O. Walter, J. I. Berkhout, R. Buchness, E. Kram, L. Rovner, and W. Ross Adey

EXPERIMENT TITLE/NUMBER: Digital Computer Analysis of Neurophysiological Data from Biosatellite III

PROGRAM/MISSION: Biosatellite III

CLASSIFICATION: Animal - Pig-tailed monkey (Macaca nemestrina)

DISCIPLINE(S): Neurosensory

OBJECTIVES: To perform a short-term analysis to assist in animal monitoring and mission abort decisions, and a long-term analysis to support general physiological studies, including circadian studies.

PROTOCOL: Data for the short-term analysis were available from telemetry captures at prime stations: Quito, Ecuador; Lima, Peru; Santiago, Chile and Fort Myers, Florida. Long-term data were available from the prime stations and postflight analyses.

EQUIPMENT: EEG, Digital magnetic tapes.

RESULTS: The launch was a mildly traumatic event for "Bonny." The animal was aroused throughout the task presentations on Days 2, 3, 4, and 5, even though the level of performance was quite low. There were strongly circadian fluctuations of brain temperature which may be related to intensity peaks of the EEG. Flight induced pathology was first noted in cortical spectra early in Day 7. During Day 8 and the first half of Day 9 the cortical spectra were stable, although abnormally low in power. On Day 9, the mission was terminated when there was a further decline in parietal intensity. Death occurred R+8 hrs, the acute cause being ventricular fibrillation.

CONCLUSIONS: The animal appears to have had a functionally intact cortex until Day 6, and to have had a functional cortical impairment on Days 7 and 8, which was compatible with a minimal response to alterations of light versus dark and with a maintenance of normal subcortical electrical activity. The animal became grossly pathological and unresponsive on Day 9. 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.

PUBLICATIONS: 2, 3, 4, 7, 557

PRINCIPAL INVESTIGATOR(S): Richard S. Young, John W. Tremor, Richard Willoughby, Robert L. Corbett, Kenneth A. Souza, and Paul D. Sebesta

EXPERIMENT TITLE/NUMBER: The Effect of Weightlessness on the Dividing Eggs of Rana pipiens, P-1047

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal - Bullfrog eggs (Rana pipiens)

DISCIPLINE(S): Genetics, Cell biology

OBJECTIVES: To determine if weightlessness affects the ability of the fertilized frog egg to divide, differentiate and develop normally.

PROTOCOL: On day F-3, 60 female frogs were injected with gonadotrophin to induce ovulation. At F-12.5 hr., stripped eggs were fertilized and divided into clusters of 5. They were then kept at 43° F to prevent division. The eggs were placed in groups of 10 in the first eight modules to be fixed, and in groups of 5 for the remainder. The experiment called for fixation at F-0, F+1 hr, F+2, F+3, F+32, F+40, F+68 hrs. The last module pair was to return with live embryos. Three hardware packages were prepared; one for flight, one for backup, and one for control.

EQUIPMENT: The package contained 16 acrylic modules divided into 2 chambers, a 10 ml egg chamber and 4 ml-fixative chamber, a coolant line around the package to maintain it at 42.5° F on the pad, thermistors to each of 4 modules, a fifth thermistor as a switch to change the temperature to 70° F at launch.

RESULTS: The first cleavage, the most sensitive to gravity, occurred before launch, due to a 3 hr. delay. No differences were observed in abnormalities between flight and Earth control eggs; they all fell well within the range of expected abnormal development. No differences in development of the frog eggs could be detected.

CONCLUSIONS: The fertilized eggs divided, differentiated, and developed normally in two days of weightlessness despite initiation of exposure at the middle of the two-cell stage.

PUBLICATIONS: 529, 530, 579, 581

PRINCIPAL INVESTIGATOR(S): Richard S. Young, and John W. Tremor

EXPERIMENT TITLE/NUMBER: Frog Egg Growth, S003

PROGRAM/MISSION: Gemini 8, 12

CLASSIFICATION: Animal - Bullfrog eggs (Rana pipiens)

DISCIPLINE(S): Cell biology, Genetics

OBJECTIVES: To determine the effect of weightlessness on the ability of a fertilized frog egg to divide normally and to differentiate and form a normal embryo.

PROTOCOL: Eggs were obtained from female frogs after they were injected with pituitary gland extract at F-48 hrs. The eggs were fertilized and placed in 10 cc of spring water in four chambers, with five eggs per chamber at 43°F. Two sets of ground controls were used, one simultaneous and one with a two hr delay. A temperature of 66° to 74°F was maintained inflight. Two chambers were fixed with formalin after 41 hrs of flight, one was fixed after 85 hrs and one chamber was unfixed with embryos being recovered alive.

EQUIPMENT: Experiment package with four chambers, a temperature control system and two handles for fixative activation.

RESULTS: On Gemini 8, early cleavage was achieved but the flight was too short to achieve later developmental stages. On the Gemini 12 experiment, ten embryos in 41 hr. fixation were morphologically normal when compared to controls. Embryos at 85 hr. fixation were well developed and morphologically normal tadpoles. Five unfixed embryos were live swimming tadpoles. Three of these were morphologically normal, two were abnormal, but consistent with ground controls. These live tadpoles died for unknown reasons several hours after recovery.

CONCLUSIONS: A gravitational field is not necessary for frog eggs to divide normally, nor is it necessary for differentiation and morphological changes in later stages of embryonic development.

PUBLICATIONS: 529, 530, 580, 581

PRINCIPAL INVESTIGATOR(S): Richard S. Young, and John W. Tremor

EXPERIMENT TITLE/NUMBER: Sea Urchin Egg Fertilization and Development, SC02

PROGRAM/MISSION: Gemini 3

CLASSIFICATION: Animal - Sea urchin eggs (Arbacia punctulata)

DISCIPLINE(S): Cell biology, Genetics

OBJECTIVES: To investigate the effects of subgravity on fertilization, cell division, differentiation, and growth of a relatively simple biological system.

PROTOCOL: The specimens in 4 chambers were fertilized preflight. The other specimens were fertilized shortly after orbital insertion. Growth of specimens in each group of fertilized eggs was inhibited at different stages of development by the addition of fixative solution. A ground control package was treated identically.

EQUIPMENT: A cylinder of eight specimen chambers, each divided into 3 compartments so that the sperm, ova, and fixative solutions were separated. Rotation of a handle actuated either fertilization or fixation.

RESULTS: The experiment was flown and recovered as scheduled. However, the experiment objectives were not achieved, primarily for mechanical reasons. The operating mechanism for the package failed, and the handle did not actuate the device. There also may have been leakage in the formalin (fixative) chamber sufficient to damage the eggs.

CONCLUSIONS: Insufficient data - inconclusive.

PUBLICATIONS: 581, 582

PRINCIPAL INVESTIGATOR(S): Herbert M. Conrad

EXPERIMENT TITLE/NUMBER: A Study of the Effect of Weightlessness on the Biochemical Response of a Monocotyledonous Seedling, P-1138

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Plant - Wheat seedlings (*Triticum vulgare*)

DISCIPLINE(S): Behavioral science, Cell biology

OBJECTIVES: To correlate changes in metabolism and energetics with the re-orientation of plant organs during weightlessness and to study the key enzymes associated with these processes.

PROTOCOL: Seventy-eight wheat seeds weighing 38-39 mg were used in both the flight package and Earth controls. The seeds were surface-sterilized in 0.05% Hg Cl<sub>2</sub> and soaked for 3 hours in distilled water at 95° F. The seedlings were placed in polycarbonate stalks containing wet vermiculite. Gas samples were taken and the lids 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.

EQUIPMENT: Experiment package, cytospectrophotometer.

RESULTS: Increased GLU-6-P dehydrogenase, GLY-3-P dehydrogenase, and peroxidase was noted. No change was found in malic acid dehydrogenase, transaminase, or cytochrome C reductase. Enzyme kinetics and distribution were normal.

CONCLUSIONS: The growth of wheat seedlings in space appeared normal. The growth on the clinostat simulated growth in a weightless environment. However, only auxin-mediated reactions were simulated by growth on the horizontal clinostat. The increased enzyme activity was found to be physiologic and not due to structural changes in enzymes while in the weightless state. The kinetic studies indicated that space flight does not affect the affinity of an enzyme for its substrate.

PUBLICATIONS: 133, 134

PRINCIPAL INVESTIGATOR(S): Howard J. Curtis, and Harold H. Smith

EXPERIMENT TITLE/NUMBER: Effect of HZE Particles on Corn Seeds

PROGRAM/MISSION: Discoverer XXXII

CLASSIFICATION: Plant - Corn seeds (Zea mays)

DISCIPLINE(S): Radiobiology

OBJECTIVES: To verify predicted radiobiologic effects of heavy cosmic ray primary particles (HZE particles) on corn seeds.

PROTOCOL: The corn seeds (of a special genetic stock for coloration change from green to yellow) were flown in the Discoverer spacecraft, recovered, and examined for genetic defects. A control package was kept under similar conditions.

EQUIPMENT: Container for corn seeds.

RESULTS: There were no differences between the flight samples and control samples.

CONCLUSIONS: The impact of HZE on genes in corn is minimal. No genetic defects were observed.

PUBLICATIONS: 139

PRINCIPAL INVESTIGATOR(S): M. Delpoux, Horst Buecker, S. Fogel, M. Freeling, E. H. Graul, G. Horneck, A. R. Kranz, H. Paniel, W. Ruether, U. Scheidemann, C. Thomas, C. A. Tobias, B. Toth, T. Yang, O. C. Allkofer, R. Beaujean, E. V. Benton, W. Enge, R. Facius, H. Francois, W. Heinrich, D. Hildebrand, C. Jacquot, R. Kaiser, J. P. Massue, E. Obst, D. D. Peterson, R. Pfohl, G. Portal, G. Reitz, E. Schopper, M. Schaefer, J. U. Schott, and G. Siegmon

EXPERIMENT TITLE/NUMBER: BIOSTACK III

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Plant - Tobacco seeds (Nicotiana tabacum)

DISCIPLINE(S): Radiobiology, Cell biology, Behavioral science

OBJECTIVES: To study the influence of HZE particles on germination, growth and development, and mutation induction.

PROTOCOL: The BIOSTACK flight experiment was stored in the R-1 compartment of the Apollo capsule where there was the least shielding from ambient radiation. The specimens were arranged in monolayers, imbedded in polyvinyl alcohol, and stacked between track detector sheets. Particle tracks were located in relation to biological objects and the physical quantities of these particles were determined.

EQUIPMENT: Two cylindrical aluminum containers which enclosed a stack of biological specimens and dosimeters.

RESULTS: Results were unavailable (presumably no effect). 78 HZE hits scored 2,328 seeds.

CONCLUSIONS: HZE-particle-induced damage might become manifest if nonreplaceable cells were destroyed. In manned space flight, the primary concern was the nervous system. However, the risk to man from HZE particles during space flight can be sufficiently lowered if the maximum possible shielding against HZE particle bombardment is ensured in the design and construction of future space vehicles.

PUBLICATIONS: 121, 122, 212

PRINCIPAL INVESTIGATOR(S): Stephen W. Gray, and Betty F. Edwards

EXPERIMENT TITLE/NUMBER: The Effect of Weightlessness on the Growth and Orientation of Roots and Shoots of Monocotyledonous Seedlings, P-1020

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Plant - Wheat seedlings (Triticum vulgare)

DISCIPLINE(S): Behavioral science, Cell biology

OBJECTIVES: To determine alterations in the position of statolith starch grains, the pattern of mitosis and cell elongation, and the biochemistry of the seedlings in a weightless environment, and to determine if weightlessness is adequately simulated by the clinostat.

PROTOCOL: Seventy-eight wheat seeds weighing 38-39 mg were used in both the flight package and Earth controls. The seeds were surface-sterilized in 0.05%  $HgCl_2$  and soaked for 3 hours in distilled water at 95° F. The seedlings were placed in polycarbonate stalks containing wet vermiculite. Gas samples were taken and the lids were sealed. All growth took place in darkness.

EQUIPMENT: Experiment package.

RESULTS: Inflight germination was unaffected. Coleoptile height was greater after 58 and 65 hours than control. 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.

CONCLUSIONS: Short periods of space flight do not disorganize the normal processes of the growing wheat seedling. Only small deviations from normal physiology or behavior were observed, most of them returning to normal after several hours. The Earth bound clinostat may be a tool for predicting some of the responses to weightlessness in suitable organisms.

PUBLICATIONS: 174, 175, 176, 177, 178, 179, 180, 181, 214, 215

PRINCIPAL INVESTIGATOR(S): John E. Hewitt

EXPERIMENT TITLE/NUMBER: Radiation Exposures During the Biosatellite II Flight

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal, Plant, Microorganism

DISCIPLINE(S): Radiobiology

OBJECTIVES: To determine the combined effects of radiation and weightlessness on lethality and mutagenesis in a variety of living systems.

PROTOCOL: The biologic material from each experiment was divided into four groups; flight groups irradiated and non-irradiated, and Earth control groups irradiated and non-irradiated.  $^{85}\text{Sr}$  was used as the radiation source and Lithium fluoride (LiF) thermoluminescent powder was selected as the primary dosimeter. The packages were placed in the capsule at different distances from the source so that each would receive its correct exposure.

EQUIPMENT: Capsule, experiment packages, nuclear emulsion package, backscatter shield, heat shield, source holder.  $^{85}\text{Sr}$  source, LiF powder dosimeters,  $\text{CaF}_2$  dosimeters.

RESULTS: The radiation exposures in the control areas were quite low. Few were above 0.5 R. From nuclear emulsion measurements, an upper limit dose due to protons was  $40 \text{ mR}$  for the mission. There were  $10.1$  traversals of atomic nuclei of  $Z \geq 20/\text{cm}^2$  during the mission.

CONCLUSIONS: Nuclear emulsion measurements verified that radiation doses due to space radiations are very low in orbits similar to that of Biosatellite II. It is highly unlikely that any difference found between the biologic responses of the same experiment in the flight and Earth control capsules could be attributed to radiation exposure differences, nor could any unusual results be attributed to the presence in the capsules of a large component of low-energy radiation produce by multiple scattering.

PUBLICATIONS: 268

PRINCIPAL INVESTIGATOR(S): Samuel P. Johnson

EXPERIMENT TITLE/NUMBER: Biochemical Changes in the Endosperm of Wheat Seedlings in the Weightless State, P-1138

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Plant - Wheat seedlings (Triticum vulgare)

DISCIPLINE(S): Behavioral science, Cell biology

OBJECTIVES: To determine if weightlessness retards the growth of the root and shoot because of a modification of protein synthesis and the incorporation of carbohydrates into cell wall constituents of the endosperm of the wheat seedling.

PROTOCOL: Seventy-eight wheat seeds weighing 38-39 mg were used in both the flight package and Earth controls. The seeds were surface-sterilized in 0.05% HgCl<sub>2</sub> and soaked for 3 hours in distilled water at 95°F. The seedlings were placed in polycarbonate stalks containing wet vermiculite. Gas samples were taken and the lids were sealed. All growth took place in the dark.

EQUIPMENT: Experiment package.

RESULTS: No significant differences were found in carbohydrate distribution, starch, sucrose, glucose, total or protein nitrogen comparing endosperms of the control and flight seedlings.

CONCLUSIONS: The biochemical analyses of wheat seedling endosperms did not reveal any differences in the concentrations of carbohydrates, amino acids, and nitrogen fractions in the control and flight samples. It was postulated that the orbital flight was not of sufficient duration to elicit a response.

PUBLICATIONS: 302

PRINCIPAL INVESTIGATOR(S): Samuel P. Johnson, and T. W. Tibbitts

EXPERIMENT TITLE/NUMBER: The Liminal Angle of Plagiogeotropic Organ Under Weightlessness, P-1017

PROGRAM/MISSION: Biosatellite #1

CLASSIFICATION: Plant - Pepper plant (Capsicum annuum)

DISCIPLINE(S): Behavioral science, Cell biology

OBJECTIVES: To determine if a weightless environment would produce results in plants similar to those noted in response to rotation on a horizontal clinostat, i.e., the liminal angle will be decreased, accompanied by a differential mobilization of carbohydrates and amino acids.

PROTOCOL: Four 35 day old plants were flown and photographed at ten-minute intervals during orbit. Five auxiliary 25 day old plants were placed inside the unit for carbohydrate, amino acid and nitrogen analyses. Two control groups of plants were subjected to horizontal and vertical rotation on the clinostat and one control group served as a radiation mockup. 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. The plants were also subjected to acoustic levels that simulated the launch and recovery flight environments.

EQUIPMENT: Flight package with a camera positioned in the center of four plants which, through a three-mirror optical system, photographed the four plants from the side and top. Illumination was provided by 15-watt incandescent lamps, producing 200 foot-candles of light for 5 sec. every 10 min. The unit weighed 12 pounds.

RESULTS: A reduction in the liminal angle of the petiole with the stem was found and was similar to that produced in the laboratory using the horizontal clinostat. The carbohydrates were similar in concentration in the control and orbital plants, but the amino acid change was greater in the orbital plants.

CONCLUSIONS: Carbohydrates and, to some extent, amino acids play a direct role in the response of plants to geoinduction. The carbohydrates presumably provided energy for the accelerated growth and/or elongation of the cells along the convex curvature of the plagiogeotropic organ, thereby resulting in a decrease in the liminal angle.

PUBLICATIONS: 9, 133, 303

PRINCIPAL INVESTIGATOR(S): A. R. Kranz, U. Scheidemann, C. Thomas, Horst Buecker, M. Delpoux, S. Fogel, M. Freeling, E. H. Graul, G. Horneck, H. Planel, W. Ruether, C. A. Tobias, B. Toth, T. Yang, O. C. Allkofer, R. Beaujean, E. V. Benton, W. Enge, R. Facius, H. Francois, W. Heinrich, D. Hildebrand, C. Jacquot, R. Kaiser, J. P. Massue, E. Obst, D. D. Peterson, R. Pfohl, G. Portal, G. Reitz, E. Schopper, M. Schaefer, J. U. Schott, and G. Siegmon

EXPERIMENT TITLE/NUMBER: BIOSTACK III

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Plant - European watercress seeds (Arabidopsis thaliana)

DISCIPLINE(S): Radiobiology, Cell biology, Behavioral science

OBJECTIVES: To observe the influence of HZE particles on germination, plant development, and mutation induction.

PROTOCOL: The BIOSTACK flight experiment was stored in the R-1 compartment on the Apollo capsule where there was the least shielding from ambient radiation. The specimens were arranged in monolayers, imbedded in polyvinyl alcohol, and stacked between track detector sheets. Particle tracks were located in relation to biological objects and the physical quantities of these particles were determined.

EQUIPMENT: Two cylindrical aluminum containers which enclosed a stack of biological specimens and dosimeters.

RESULTS: There was no significant difference between HZE hit plants and controls.

CONCLUSIONS: HZE-particle-induced damage might become manifest if nonreplaceable cells are destroyed. In manned space flight, the primary concern would be the nervous system. However, the risk to man from HZE particles during space flight can be sufficiently lowered if the maximum possible shielding against HZE particle bombardment is ensured in the design and construction of future space vehicles.

PUBLICATIONS: 116, 121, 122, 124, 212, 469

PRINCIPAL INVESTIGATOR(S): Charles J. Lyon

EXPERIMENT TITLE/NUMBER: Growth Physiology of the Wheat Seedling in Space,  
P-1096

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Plant - Wheat seedlings (Triticum vulgare)

DISCIPLINE(S): Behavioral science, Cell biology

OBJECTIVES: To determine whether seeds would produce normal seedlings, change orientation, rate of growth, or germination in weightlessness.

PROTOCOL: Seventy-eight wheat seeds weighing 38-39 mg were used in both the flight package and Earth controls. The seeds were surface-sterilized in 0.05% HgCl<sub>2</sub> and soaked for 3 hours in distilled water at 95°F. The seedlings were placed in polycarbonate stalks containing wet vermiculite. Gas samples were taken and the lids were sealed. All growth took place in the dark. Angle measurements were made to record root orientation.

EQUIPMENT: Experiment package, photographic equipment.

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 to be reflected in growth rates or external morphology of roots and coleoptiles.

CONCLUSIONS: The apparent lack of disturbance of the basic metabolic processes which supply the energy for normal growth 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.

PUBLICATIONS: 363, 364, 365, 366

PRINCIPAL INVESTIGATOR(S): Cheryl Peltz

EXPERIMENT TITLE/NUMBER: Cytoplasmic Streaming, ED63

PROGRAM/MISSION: Skylab 3, 4

CLASSIFICATION: Plant - Water weed (Elodea)

DISCIPLINE(S): Cell biology

OBJECTIVES: To investigate the effects of null gravity on the cytoplasmic streaming of the Elodea plant.

PROTOCOL: For each mission, vials containing Elodea sprigs suspended in a nutrient agar solution were prepared for flight and ground control. The flight vials were sealed at 5 psia in an altitude chamber. Preflight tests were conducted to determine the optimum nutrient constituents, and the effect of light, darkness, temperature and vibration on the viability of Elodea. The basic results were that temperatures between 18°C and 34°C, light levels of 15 to 25 foot candles, and six days or less of darkness, followed by exposure to light would have no deleterious effects on Elodea.

EQUIPMENT: Vials, microscope slides, cover slips, tweezers, microscope, microscope-camera adapter, 16mm motion picture camera.

RESULTS: The plants flown on Skylab 3 died before photographs could be obtained after 15 days of flight, probably because of 2 unscheduled days of darkness due to experiment scheduling difficulties. The control plants having an identical schedule were also dead. The experiment was reflown on Skylab 4. On the 11th day of that mission, cytoplasmic streaming was observed. By the 18th day, these plants had also died. Microscopic photography was not successful due to the removal of a 10-power microscope eye piece and improper exposure of the film.

CONCLUSIONS: In addition to the problems of excessive dark periods, it may have been difficult for the plant's waste products to diffuse away from the leaf surface in zero gravity. They may have "smothered" in oxygen, unable to obtain the necessary carbon dioxide for photosynthesis. It was suggested that for future experiments with aquatic plants, a water environment be used.

PUBLICATIONS: 197, 377, 500

PRINCIPAL INVESTIGATOR(S): E. Reinholz, Horst Buecker, R. Kaiser, J. P. Massue, R. Pfohl, W. Enge, O. C. Allkofer, K. Bartholomae, R. Beaujean, W. Heinrich, K. Fukui, Eugene V. Benton, E. Schopper, G. Henig, J. U. Schott, H. Francois, and G. Portal

EXPERIMENT TITLE/NUMBER: BIOSTACK I, II

PROGRAM/MISSION: Apollo 16, 17

CLASSIFICATION: Plant - European water cress seeds, (Arabidopsis thaliana)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To study the biological effects of individual heavy nuclei with high energy loss (HZE); to obtain as much information as possible on the mechanisms of biological damage by HZE particles; to measure the charge and energy spectra of cosmic radiation within the Apollo Command Module; and to provide data to allow an estimate of the hazard to man from space radiation.

PROTOCOL: Bacterial spores, protozoan cysts, plant seeds, shrimp eggs, and insect eggs were studied for inhibition of germination, inhibition of cell growth, inhibition of organ development, developmental anomalies in various stages of growth, and mutation induction using several physical radiation detectors. The BIOSTACK unit was flown in the Command Module where shielding to ambient cosmic radiation was minimal. Postflight, the ground controls and the flight package were disassembled and particle hits were graphed.

EQUIPMENT: Hermetically sealed aluminum container, containing a series of select biologic material each sandwiched between several types of dosimeters (nuclear emulsions, cellulose nitrate, polycarbonate, LiF), and thermistors.

RESULTS: The plant germinated with the same frequency as the Earth-controls (84%). However, the frequency of multicaulous plants grown from hit<sub>4</sub> seeds was much higher than the controls. There were 18 HZE hits scored/2 X 10<sup>4</sup> seeds.

CONCLUSIONS: The experiment confirms the assumption that HZE particle-induced damage might become manifest if a significant number of nonreplaceable cells are destroyed.

PUBLICATIONS: 28, 113, 114, 115, 117, 118, 119, 120, 185, 186, 213, 420, 469

PRINCIPAL INVESTIGATOR(S): W. Scheuermann, Horst Buecker, R. Kaiser, J. P. Massue, R. Pfohl, W. Enge, O. C. Allkofer, K. Bartholomae, R. Beaujean, W. Heinrich, K. Fukui, Eugene V. Benton, E. Schopper, G. Henig, J. U. Schott, H. Francois, and G. Portal

EXPERIMENT TITLE/NUMBER: BIOSTACK I

PROGRAM/MISSION: Apollo 16

CLASSIFICATION: Plant - Bean embryos (*Vicia faba*)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To study the biological effects of individual heavy nuclei with high energy loss (HZE), to obtain as much information as possible on the mechanisms of biological damage by HZE particles, to measure the charge and energy spectra of cosmic radiation within the Apollo Command Module, and to provide data to allow an estimate of the hazard to man from space radiation.

PROTOCOL: Bacterial spores, protozoan cysts, plant seeds, shrimp eggs and insect eggs were studied for inhibition of germination, inhibition of cell growth, inhibition of organ development, developmental anomalies in various stages of growth, and mutation induction using several physical radiation detectors. The BIOSTACK unit was flown in the Command Module where shielding to ambient cosmic radiation was minimal. After the flight, the ground controls and the flight package were disassembled and particle hits were graphed.

EQUIPMENT: Hermetically sealed aluminum container, containing a series of select biologic material, each sandwiched between several types of dosimeters (nuclear emulsions - K2 and K5, cellulose nitrate, polycarbonate, LiF), and thermistors.

RESULTS: Embryos showed no growth differences. There were no HZE influences on nuclear material. No effect was found on achromasia or DNA repair.

CONCLUSIONS: Biological material was not harmed by HZE radiation. If any destruction occurred, it is likely that surrounding intact cells replaced destroyed cells.

PUBLICATIONS: 113, 114, 115, 116, 118, 119, 120, 185, 213, 420

PRINCIPAL INVESTIGATOR(S): Arnold H. Sparrow, Lloyd A. Schairer, and  
Kodumundi M. Marimuthu

EXPERIMENT TITLE/NUMBER: Radiobiological Studies of Tradescantia Plants  
Orbited in Biosatellite II, P-1123

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Plant - (Tradescantia)

DISCIPLINE(S): Radiobiology, Genetics, Behavioral science, Cell biology

OBJECTIVES: To determine the effect of weightlessness and other spacecraft environmental conditions on spontaneous and radiation-induced somatic mutation rates and on selected cytologic changes.

PROTOCOL: Data obtained from irradiated and nonirradiated flight plants were compared with data from nonflight irradiated and nonirradiated control plants. Thirty-two plants were flown in a package in the spacecraft behind the radiation shield, and identical nonflight control packages (with and without irradiation) were maintained at the launch site. All these plants were observed after the flight for: (1) somatic mutation (blue to pink or colorless cells); (2) cell size (giant and 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.

EQUIPMENT: Experimental packages constructed of polypropylene plastic, each designed to hold 32 plants with roots sealed in a tube filled with nutrient solution, thermistor, dosimeters (LiF).

RESULTS: Irradiated and nonirradiated flight plants were compared with comparable controls. Bud blasting with flower opening was noted R+8. No differences in cell size, chromosome aberration or somatic mutation were found. Irradiated flight plants showed increased pollen abortion, pollen micronuclei and stamen hair stunting. Disturbed spindle function of root tips was observed. The Earth irradiated had higher mutation rate than flight. Mutation rates were equal for nonirradiated material. Inflight dosimetry to root zone was 125-285r, 218-225r in bud zone.

CONCLUSIONS: Clearly differences exist between flight and nonflight material and the significance and possible mechanisms for these effects are being studied in continuing nonflight tests in an effort to better assess the possible hazards to living systems of the stresses encountered during orbital flight.

PUBLICATIONS: 375, 376, 468, 494, 495, 496, 497

**PRINCIPAL INVESTIGATOR(S):** Cornelius A. Tobias, Tracy C. H. Yang, M. Freeling, S. Fogel, Horst Buecker, M. Delpoux, E. H. Graul, G. Horneck, A. R. Kranz, H. Planel, W. Ruether, U. Scheidemann, C. Thomas, B. Toth, O. C. Allkofer, R. Beaujean, E. V. Benton, W. Enge, R. Facius, H. Francois, W. Heinrich, D. Hildebrand, C. Jacquot, R. Kaiser, J. P. Massue, E. Obst, D. D. Peterson, R. Pfohl, G. Portal, G. Reitz, E. Schopper, M. Schaeffer, J. U. Schott, and G. Siegmon

**EXPERIMENT TITLE/NUMBER:** BIOSTACK III

**PROGRAM/MISSION:** Apollo-Soyuz Test Project

**CLASSIFICATION:** Plant - Corn seeds (Zea mays)

**DISCIPLINE(S):** Radiobiology, Cell biology, Behavioral science

**OBJECTIVES:** To study the influence of HZE particles on growth, differentiation and morphogenesis, and mutation induction.

**PROTOCOL:** The BIOSTACK flight experiment was stored in the R-1 compartment on the Apollo capsule where there was the least shielding from ambient radiation. The specimens were arranged in monolayers, imbedded in polyvinyl alcohol, and stacked between track detector sheets. Particle tracks were located in relation to biological objects and the physical quantities of these particles were determined.

**EQUIPMENT:** Two cylindrical aluminum containers which each enclosed a stack of biological specimens and dosimeters.

**RESULTS:** Growth and development of some seeds hit by HZE was retarded, but it was not significant. Results are incomplete. Of 160 seeds, 90 were hit.

**CONCLUSIONS:** HZE-particle-induced damage might become manifest if nonreplaceable cells are destroyed. In manned space flight, the primary concern would be the nervous system. However, the risk to man from HZE particles during space flight can be sufficiently lowered if the maximum possible shielding against HZE particle bombardment is ensured in the design and construction of future space vehicles.

**PUBLICATIONS:** 28, 39, 116, 121, 122, 124, 185, 186, 188, 212, 419, 420

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PRINCIPAL INVESTIGATOR(S): Joel G. Wordekemper, and Donald W. Schlack

EXPERIMENT TITLE/NUMBER: Plant Growth - Plant Phototropism, ED61/62

PROGRAM/MISSION: Skylab 3

CLASSIFICATION: Plant - Rice seedlings

DISCIPLINE(S): Behavioral science, Cell biology

OBJECTIVES: To compare root and stem growth and orientation in null gravity with growth and orientation on Earth and to determine if visible light (phototropism) in null gravity can substitute for geotropism (gravitational effect).

PROTOCOL: Twenty-four seeds were grown in a container with eight cells, each having two windows. One window was covered with a neutral density filter, and one with a removable opaque cover. Removal of the opaque covers permitted observation and photography of plant growth. Each of the eight cells had a different filter ranging from a transmittance of 1 (clear) to 0 (opaque). Each cell was filled with a sterile nutrient agar. A mechanical seeder was built to implant three seeds in each cell while in orbit with a minimum removal of agar. A special camera bracket held the camera at the proper distance from the plants during photography of seed development

EQUIPMENT: Experiment package, camera.

RESULTS: The direction of growth was extremely irregular with stems making 180-degree turns away from the light and many plant tips demonstrated curled patterns. The stems seemed to exhibit no phototropic effect. Some grew toward the light, some away from it. The illumination level did not appear to be a contributing factor to the growth rates of the small sample of seeds.

CONCLUSIONS: The proposed explanation for the lack of any phototropic effect by the rice seeds is that the auxin distribution system of the plant relies upon gravity. Auxins are plant growth hormones that cause cells to elongate or grow. They are produced in the tips of both the stems and the roots and are distributed away from the tip into the "area of elongation." Without gravity, the auxins may have been distributed unevenly, with pockets collecting somewhat randomly, causing irregular stem and root growth. It is also possible that the light sensing mechanism in the stem tip that triggers the auxin distribution reacted differently in zero-gravity but this mechanism is not understood well enough to hypothesize its reaction to zero-gravity.

PUBLICATIONS: 197, 377, 500

**PRINCIPAL INVESTIGATOR(S):** Michael A. Bender, Frederick J. deSerres, P.  
Carolyn Gooch, I. R. Miller, D. B. Smith and Sohei  
Kondo

**EXPERIMENT TITLE/NUMBER:** Radiation and Zero-Gravity Effects on Human  
Leukocytes and Neurospora crassa, S004

**PROGRAM/MISSION:** Gemini 3, 11

**CLASSIFICATION:** Human, Microorganism

**DISCIPLINE(S):** Radiobiology, Hematology, Cell biology, Genetics

**OBJECTIVES:** To determine if there is any synergism between radiation and space flight in white blood cells, and in Neurospora crassa, and if there are any large radiobiological effects following space flight.

**PROTOCOL:** Whole human blood and Neurospora crassa spores were irradiated with <sup>32</sup>P B-rays during orbit. Irradiation was accomplished by identical experimental devices, one on the righthand hatch of the spacecraft, and one on the ground. Upon completion, a cytogenetic analysis was made of each blood sample, and the frequencies of chromosome aberration determined. Yields of both single and multiple break aberrations were calculated for the flight and ground-control samples. Survival of the spores and mutability of two different genes were studied for frequencies of chromosome breakage and of gene mutation. Spore samples were irradiated on the surface of filters and in suspension form. Gemini 3 carried only human blood while Gemini 11 carried both specimens.

**EQUIPMENT:** <sup>32</sup>P source, aluminum blood-sample holder, dosimeter rods.

**RESULTS:** A synergism between radiation and some space flight parameters appeared to exist for human chromosome aberration production on the Gemini 3 flight. It seems likely that this effect is on the normal restitution of chromosome breaks. Both the Gemini 11 blood experiment and the Neurospora crassa experiment failed to result in data confirmatory of the apparent synergism observed on the Gemini 3 mission.

**CONCLUSIONS:** The two parts of this experiment have shown that neither orbital space flight nor any of the stresses connected with it produced significant, unpredicted genetic damage, at least insofar as chromosomal aberration production is a valid measure of this general type of effect.

**PUBLICATIONS:** 30, 31, 32, 33, 34, 145, 149, 152

PRINCIPAL INVESTIGATOR(S): Lee R. Brown, William J. Frome, Sandra Handler,  
Merrill G. Wheatcroft, and Linda J. Rider

EXPERIMENT TITLE/NUMBER: Skylab Oral Health Studies

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Environmental health

OBJECTIVES: To maintain oral health.

PROTOCOL: During all missions, provision was made for an extension of the crewmen's home care program and equipment. Training was provided to all astronauts for self-treatment inflight should the need arise.

EQUIPMENT: Inflight Medical Support System Dental Kit.

RESULTS: Evaluation of Skylab crewmembers for mission related effects on oral health in relation to possible dental injuries provided the following distinctive changes: (1) increased counts of specific anaerobic and streptococcal components; (2) elevations in levels of secretory IgA concurrent with diminutions of salivary lysozyme, and (3) increases in dental calculus and gingival inflammations.

CONCLUSIONS: The most significant finding from these investigations was the relative nonexistence of health hazardous intraoral changes. The clinical changes are considered to be more influenced by the preexisting state of dental health than by any mission related effects.

PUBLICATIONS: 92, 93, 94

PRINCIPAL INVESTIGATOR(S): Irving Davis

EXPERIMENT TITLE/NUMBER: Radiobiology Experiments in Discoverer Satellites.  
II. Clostridia Spore Labilization: A Biological  
System to Quantitate Raciation

PROGRAM/MISSION: Discoverer XVII, XVIII

CLASSIFICATION: Microorganism (Clostridium sporogenes)

DISCIPLINE(S): Cell biology, Radiobiology

OBJECTIVES: To provide a means of quantitating and correlating space radiations with microbiological activity.

PROTOCOL: Aliquots of cell suspensions of  $4 \times 10^3$  cell/ml were delivered to 2.0 ml ampules and heat sealed. All cultures were stored at  $5^{\circ}\text{C}$  until used. Caramelized glucose, pH 7.5, was used as the medium to test for labilization for the spores. Postflight, the vials were opened, and analyzed for growth.

EQUIPMENT: Caramelized glucose, glass ampules, refrigeration units for the ground, thermistors, track plates, chemical dosimeters, needle sets.

RESULTS: The probable dose received on Discoverer XVII was 40-50 rad with 71% inhibition noted postflight. On Discoverer XVIII, the probable dose was less than 0.1 rad with 12% inhibition of postflight growth.

CONCLUSIONS: Laboratory studies have shown that when similar spores are exposed to radiation and subsequently treated with caramelized glucose, the labilization effect is quantitatively inhibited. The same effect was observed in the flight samples. This experiment shows the usefulness of Clostridia for study of space radiation hazards.

PUBLICATIONS: 140, 141

PRINCIPAL INVESTIGATOR(S): A. Gib DeBusk

EXPERIMENT TITLE/NUMBER: Genetic Experiments on NERV

PROGRAM/MISSION: NERV 1

CLASSIFICATION: Microorganism - (Neurospora crassa)

DISCIPLINE(S): Cell biology, Genetics, Radiobiology

OBJECTIVES: To study the inner Van Allen radiation belt using a nuclear emulsion, and to study some biological effects of near zero gravity.

PROTOCOL: Cells were exposed to flight conditions in the lower Van Allen belt for about 26 minutes at an altitude of about 1,200 miles. Two capsules contained material designed to be assayed by means of the back mutation test. The third capsule was designed to be assayed by the forward mutation test. Three sets of controls were prepared.

EQUIPMENT: Experiment capsules.

RESULTS: The cells designated for the back mutation test were lost due to contamination. The forward mutation sample had injured cells. A 30% increase in mutation frequency was found. There was approximately a 100% increase in physiologically injured cells in the flight sample.

CONCLUSIONS: With the data, there is no way to compare the increase in mutation with a known quantity of radiation. The experiment was not designed to detect "physiological damage," but observation of this phenomena came as a by-product. Some of the damaged cells were not able to initiate the growth process, but recovered if given a complex nutrient. The recovered cells were normal. This would appear to be a case of temporary cell damage caused by some agent or condition of flight.

PUBLICATIONS: 143, 144

PRINCIPAL INVESTIGATOR(S): A. Gis DeBusk

EXPERIMENT TITLE/NUMBER: Preliminary Report of Genetic Studies on Discoverer XVIII

PROGRAM/MISSION: Discoverer XVIII

CLASSIFICATION: Microorganism - (Neurospora crassa)

DISCIPLINE(S): Cell biology, Radiobiology, Genetics

OBJECTIVES: To correlate traversal of primary cosmic rays with an increase in mutation in a population of cells lying along the track path.

PROTOCOL: A double mutant of Neurospora was used (adenineless and inositolless colonial). 75 millipore filters had 10 ml aliquots of  $8.75 \times 10^3$  cells/ml placed on them, were dried over CaCl, mounted on orientation racks, and placed on four track plates. Each plate was wrapped in polyethylene and were stored at 27°C. Two plates were ground control, and two were flight experiment plates. The plates were air mailed to SAM and subsequently flown.

EQUIPMENT: Biological track plate, millipore filters, photographic emulsion on a 2" x 2" sheet of glass, with Neurospora covered filters on top, neutron sensitive film, Ansco 552 film, antimony foil, alanine, and albumin.

RESULTS: The emulsion was faulty with no correlation of cosmic ray path and mutation being made. No forward or back mutation were observed.

CONCLUSIONS: No reverse mutation was observed at the inositol locus in either the experimental or control population examined ( $5.25 \times 10^0$  control and  $2.8 \times 10^0$  experimental). The phenomena of physiological cell injury observed in NERV 1 was not observed in the cells in Discoverer XVIII. No significant increase in forward mutation was observed in the experimental c population examined.

PUBLICATIONS: 143, 144

PRINCIPAL INVESTIGATOR(S): Frederick J. deSerres

EXPERIMENT TITLE/NUMBER: Mutagenic Effectiveness of Known Doses of Radiation in Combination with Zero Gravity on Neurospora crassa, P-1037

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Microorganism - (Neurospora crassa)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To study the genetic effects of spaceflight alone and in combination with known doses of radiation.

PROTOCOL: A genetically marked two-component 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 dose-response curves.

EQUIPMENT: Millipore filters, LiF disk dosimeter, porous retaining rings (sample holder), module of sample holders, <sup>90</sup>Sr source, thermistor.

RESULTS: There was no difference between the flight and Earth control samples for survival, the overall induction of ad-3 mutations, or for point mutations or chromosome deletions.

CONCLUSIONS: The effects of weightlessness on radiation-induced genetic damage are complex. Both antagonistic and synergistic effects of radiation 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.

PUBLICATIONS: 145, 146, 147, 148, 150, 151, 152, 153

PRINCIPAL INVESTIGATOR(S): R. Facius, D. Hildebrand, G. Hoeltz, G. Horneck, M. Schaefer, B. Toth, Horst Fuecker, M. Delpoux, S. Fogel, M. Freeling, E. H. Graul, A. R. Kranz, H. Planel, W. Ruether, U. Scheidemann, C. Thomas, C. A. Tobias, T. Yang, O. C. Allkofer, R. Beaujean, E. V. Benton, W. Enge, H. Francois, W. Heinrich, C. Jacquot, R. Kaiser, J. P. Massue, E. Obst, D. D. Peterson, R. Pfohl, G. Portal, G. Reitz, E. Schopper, J. U. Schott, and G. Siegmon

EXPERIMENT TITLE/NUMBER: BIOSTACK III

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Microorganism - Spores (Bacillus subtilis)

DISCIPLINE(S): Cell biology, Radiobiology, Genetics

OBJECTIVES: To study HZE particle radiation on spore outgrowth, cell development, colony formation, and mutation induction.

PROTOCOL: The BIOSTACK flight experiment was stored in the R-1 compartment in the Apollo capsule where there was the least shielding from ambient radiation. The specimens were arranged in monolayers and imbedded in polyvinyl alcohol, and stacked between track detector sheets so particle tracks could be located in relation to biological objects and the physical quantities of these particles could be determined.

EQUIPMENT: There were 2 cylindrical aluminum containers which enclosed a stack of biological specimens and dosimeters.

RESULTS: Growth was significantly reduced in spores of  $< 4$  m. This result is surprising, but important because dosimetric calculations for the  $\gamma$ -electrons predicted 0.5 m for this reduced survival. Further deviations from normal development were also observed, such as swelling of the first vegetative cell, which did not divide.

CONCLUSIONS: HZE-particle-induced damage might become manifest if nonreplaceable cells are destroyed. In manned space flight, the primary concern would be the nervous system. However, the risk to man from HZE particles during space flight can be sufficiently lowered if the maximum possible shielding against HZE particle bombardment is ensured in the design and construction of future space vehicles.

PUBLICATIONS: 116, 121, 122, 124, 188, 472

PRINCIPAL INVESTIGATOR(S): James K. Ferguson, Gerald R. Taylor, and Bernard J. Mieszkuc

EXPERIMENT TITLE/NUMBER: Microbiological Investigations

PROGRAM/MISSION: Apollo

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Environmental health

OBJECTIVES: To detect potentially pathogenic microorganisms so that associated medical problems could be identified early and preventive measures established, to identify medically important microorganisms recovered from ill crewmen to aid in diagnosis and treatment, to collect microbiological data that would aid in elucidating the response of crew microbial autoflora to the space flight environment, and to evaluate the resultant effect on the crewmember.

PROTOCOL: Back-up and flight crew were sampled of F-30, F-14, F-0, R+0 days. Samples were taken from seven body surface sites, nose, throat and mouth, urine and feces. They were maintained at 4 degrees C during transport. TSB (Trypticase soy broth) was used for aerobic analysis and VIB (veal infusion broth) for anerobic analysis. The spacecraft was also analyzed pre- and postflight. Swab samples were taken from the mouthpiece of the drink gun, pistol grips of the CMP maneuver controller, head struts, floor beneath the foot of the center couch using Ca alginate swabs. The samples were vortexed and serially diluted, plated, and incubated at 35 degrees C.

EQUIPMENT: Culturing material, swabs.

RESULTS: Approximately 4,000 microbial isolations were obtained, identified, and characterized. Variation occurred in microbial response because of ecological relationships (e.g., fungi controlling *Candida albicans* decreased inflight), host susceptibility, and external environmental factors. Spread of pathogens between crewmen was common. Preflight Command Module microorganisms were replaced by crew microorganisms during flight.

CONCLUSIONS: Spacecraft environment did not predispose crew to viral or mycoplasma induced illness.

PUBLICATIONS: 192, 502, 516

PRINCIPAL INVESTIGATOR(S): John E. Hewitt

EXPERIMENT TITLE/NUMBER: Radiation Exposures During the Biosatellite II Flight

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal, Plant, Microorganism

DISCIPLINE(S): Radiobiology

OBJECTIVES: To determine the combined effects of radiation and weightlessness on lethality and mutagenesis in a variety of living systems.

PROTOCOL: The biologic material from each experiment was divided into four groups; flight groups irradiated and non-irradiated, and Earth control groups irradiated and non-irradiated.  $^{85}\text{Sr}$  was used as the radiation source and Lithium fluoride (LiF) thermoluminescent powder was selected as the primary dosimeter. The packages were placed in the capsule at different distances from the source so that each would receive its correct exposure.

EQUIPMENT: Capsule, experiment packages, nuclear emulsion package, backscatter shield, heat shield, source holder  $^{85}\text{Sr}$  source, LiF powder dosimeters,  $\text{CaF}_2$  dosimeters.

RESULTS: The radiation exposures in the control areas were quite low. Few were above 0.5 R. From nuclear emulsion measurements, an upper limit dose due to protons was 40 mR for the mission. There were 10.1 traversals of atomic nuclei of  $Z \geq 20/\text{cm}^2$  during the mission.

CONCLUSIONS: Nuclear emulsions measurements verified that radiation doses due to space radiations are very low in orbits similar to that of Biosatellite II. It is highly unlikely that any difference found between the biologic responses of the same experiment in the flight and Earth control capsules could be attributed to radiation exposure differences, nor could any unusual results be attributed to the presence in the capsules of a large component of low-energy radiation produced by multiple scattering.

PUBLICATIONS: 268

PRINCIPAL INVESTIGATOR(S): G. Horneck, Horst Buecker, R. Kaiser, J. P. Massue, R. Pfohl, W. Enge, O. C. Allkofer, K. Bartholomae, R. Beaujean, W. Heinrich, K. Fukui, Eugene V. Benton, E. Schopper, G. Henig, J. U. Schott, H. Francois, and G. Portal

EXPERIMENT TITLE/NUMBER: BIOSTACK I, II

PROGRAM/MISSION: Apollo 16, 17

CLASSIFICATION: Microorganism - Spores (Bacillus subtilis)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To study the biological effects of individual heavy nuclei with high energy loss (HZE), to obtain as much information as possible on the mechanisms of biological damage by HZE particles, to measure the charge and energy spectra of cosmic radiation within the Apollo Command Module, and to provide data to allow an estimate of the hazard to man from space radiation.

PROTOCOL: Bacterial spores, protozoan cysts, plant seeds, shrimp eggs and insect eggs were studied using several physical radiation detectors. The BIOSTACK unit was flown in the Command Module where shielding to ambient cosmic radiation was minimal. After flight, the ground controls and the flight package were disassembled and the particle hits were graphed.

EQUIPMENT: Hermetically sealed aluminum container, containing a series of select biologic material, each sandwiched between several types of dosimeters (nuclear emulsions, cellulose nitrate, polycarbonate, LiF), and thermistors.

RESULTS: The germinating fraction of the spores hit was more than 90% in the BIOSTACK I experiment and reached nearly 100% in the BIOSTACK II experiment. This fraction did not differ significantly from that of the controls, indicating a high resistance to HZE-particle bombardment. Pseudogermination was not observed on the spore hits.

CONCLUSIONS: The Bacillus subtilis spores were not influenced by the unusual environmental parameters and factors of spaceflight.

PUBLICATIONS: 113, 114, 115, 116, 117, 118, 119, 120, 125, 126, 188, 213, 283

PRINCIPAL INVESTIGATOR(S): R. H. T. Mattoni, E. C. Keller, William T. Ebersold, F. A. Eiserling, and W. R. Romig

EXPERIMENT TITLE/NUMBER: Induction of Lysogenic Bacteria in the Space Environment, P-1135

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Microorganism - (Salmonella typhimurium, Escherichia coli)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To test the hypotheses that weightlessness both with and without gamma irradiation would not affect bacterial cell growth or induction of bacterial prophage P-22.

PROTOCOL: 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 to test the effects of (1) spaceflight, (2) three chronic gamma-irradiation dose levels and (3) temperature. Each chamber was inoculated with aliquots of a suspension of bacteria adjusted to give mean viable density of about 100 cells/ml.

EQUIPMENT: Four experiment packages, <sup>85</sup>Sr source.

RESULTS: The data on bacterial growth led to rejection of the hypotheses: space flight produced both increased density of Salmonella typhimurium when grown in liquid medium and interaction to give greater resistance to gamma irradiation at levels between 265 and 1648 R total dose (17 and 103 R per average cell generation). Tests of other variables eliminated all but weightlessness in accounting for the difference. On the basis of the T tests there was no difference in the free phage per bacterium produced under conditions of control and those of flight. The induced bacteriophage per viable bacterium showed significant differences between flight and control at two radiation levels (265 and 645 R). The flight set had consistently lower yields at all levels of radiation. The Escherichia coli experiment was incomplete since the growth phase had not reached maximum because of early call-down of Biosatellite II.

CONCLUSIONS: The growth rate of Salmonella typhimurium appeared to be more rapid during spaceflight than in the Earth controls. The free phage induction was consistently lower in the flight population versus the Earth controls. The greater bacterial densities (maximum population) are believed to be a function of random cell distribution in the liquid medium under reduced gravity conditions.

PUBLICATIONS: 381, 382

PRINCIPAL INVESTIGATOR(S): Jesse N. Phillips

EXPERIMENT TITLE/NUMBER: Experiments with Photo-Synthetic Organisms in Discoverer Vehicles

PROGRAM/MISSION: Discoverer XVII

CLASSIFICATION: Microorganism - Algae (Chlorella ellipsoidea)

DISCIPLINE(S): Cell biology

OBJECTIVES: To help provide rudimentary knowledge of biological responses to space environments.

PROTOCOL: Two ml of cell suspension from a healthy Chlorella culture were pipetted into glass vials which were heat sealed. Ground controls were also made. Vials were shipped to launch site under refrigeration. Radiation dosimetry was provided inflight. On recovery, density was determined by using a photoelectric colorimeter. Growth rate was also calculated. The samples were also tested for biochemical mutants, morphological abnormalities, and pigment changes.

EQUIPMENT: Glass vials, chemical dosimeters, modified Kratz's medium (D-17), Evelyn photoelectric colorimeter, alanine, albumin, silver-activated phosphate glass rods, Ansco 522 film, neutron sensitive film, antimony foil, nuclear track plates.

RESULTS: Laboratory and flight samples responded in identical fashion. Both samples showed the same auxotrophic mutants. There were no anomalies in growth, pattern of growth, shade of color or uniformity of pigment. There were no anomalies in pigment or morphology in the samples observed. Cell counts on flight samples, ground controls and laboratory controls corresponded closely.

CONCLUSIONS: These photosynthetic organisms are capable of living and retaining viability in a space environment. None of a number of physiological responses evaluated had been detectably harmed by exposure to space environment. It appears the algae, Chlorella ellipsoidea could survive and function as a part of a life support system when exposed to radiation levels for the orbital time period of Discoverer XVII satellite.

PUBLICATIONS: 422, 423

PRINCIPAL INVESTIGATOR(S): H. Planel, J. P. Soleilhavoup, Horst Buecker, R. Kaiser, J. P. Massue, R. Pfohl, W. Enge, O. C. Allkofer, K. Bartholomae, R. Beaujean, W. Heinrich, K. Fukui, Eugene V. Benton, E. Schopper, G. Henig, J. U. Schott, H. Francois, and G. Portal

EXPERIMENT TITLE/NUMBER: BIOSTACK II

PROGRAM/MISSION: Apollo 17

CLASSIFICATION: Microorganism - Protozoan cysts (Colpoda cuculus)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To study the biological effects of individual heavy nuclei with high energy loss (HZE), to obtain as much information as possible on the mechanisms of biological damage by HZE particles, to measure the charge and energy spectra of cosmic radiation within the Apollo Command Module, and to provide data to allow an estimate of the hazard to man from space radiation.

PROTOCOL: Bacterial spores, protozoan cysts, plant seeds, shrimp eggs and insect eggs were studied for inhibition of germination, inhibition of cell growth, inhibition of organ development, developmental anomalies in various stages of growth, and mutation induction using several physical radiation detectors. The BIOSTACK unit was flown in the Command Module where shielding to ambient cosmic radiation was minimal. After the flight, the ground controls and the flight package were disassembled and particle hits were graphed.

EQUIPMENT: Hermetically sealed aluminum container, containing a series of select biologic material each sandwiched between several types of dosimeters (nuclear emulsions, cellulose nitrate, polycarbonate, LiF), and thermistors.

RESULTS: None identified.

CONCLUSIONS: None identified.

PUBLICATIONS: 113, 115, 116, 117, 119, 120, 213

PRINCIPAL INVESTIGATOR(S): Thomas D. Rogers, Margaret E. Brower, and Gerald R. Taylor

EXPERIMENT TITLE/NUMBER: Zone-Forming Fungi, MA-147

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Microorganism - Fungi (Streptomyces levoris)

DISCIPLINE(S): Cell biology, Chronobiology

OBJECTIVES To study alternating vegetative mycelial and spore ring periodicity during space flight.

PROTOCOL: Cultures were initiated by single point inoculation of spores on an agar-based medium in 60 by 5-mm petri dishes F-6. Phasing was accomplished in both the U.S. and U.S.S.R. by using a 12-hour light-dark period (100 to 200 lux). Cultures were selected and placed in space flight devices F-2 for U.S. samples and day of launch for U.S.S.R. samples. Two cultures were flown and two were used as ground controls. Cultures were maintained at 300K in an incubator during the entire experiment. Spore ring morphology was periodically documented by inflight photography.

EQUIPMENT: Radiation detectors of Lexan and cellulose acetate, petri dishes, incubator, camera.

RESULTS: A decreased growth-rate periodicity was observed inflight. One of the four cultures grown in the reduced temperature environment of the Apollo spacecraft had a growth rate more rapid than ground controls. Three of the space flight cultures developed double spore rings during the period immediately after flight. An absence of spores in portions of one ring was noted. No visible evidence of wedges in the cultures that would suggest occurring or radiation induced mutagenic alteration was observed.

CONCLUSIONS: Space flight did not affect the biorhythm of Streptomyces levoris negative and spore phases. However, the extent to which these cultures were affected cannot be accurately determined because of the action of such variables as temperature, nutritional medium, and the physical force factors associated with the launch and recovery process.

PUBLICATIONS: 448, 449, 450, 505

PRINCIPAL INVESTIGATOR(S): Robert Staehle

EXPERIMENT TITLE/NUMBER: Bacteria and Spores, ED31

PROGRAM/MISSION: Skylab 2, 4

CLASSIFICATION: Microorganism - (Bacillus subtilis, Escherichia coli),  
(Bacillus mycooides)

DISCIPLINE(S): Cell biology

OBJECTIVES: To observe and photograph bacterial colonies to determine if null gravity has any effect on survival, growth rate, mutations and morphology.

PROTOCOL: The bacteria were suspended in a water solution of polyvinyl alcohol (PVA) and were placed on a disk of filter paper. Fifteen petri dishes containing nutrient agar, together with one petri dish containing 15 filter disks of bacteria were flown. Inflight, a single bacteria and spore impregnated disk was placed in each agar-filled petri dish and incubated at 77 F for 68 hours on Skylab 2 and 88 hours on Skylab 4. Bacillus subtilis and Escherichia coli were flown on Skylab 2. Bacillus subtilis and Bacillus mycooides were used for the Skylab 4 experiment. Color photographs were made periodically throughout incubation.

EQUIPMENT: Petri dishes and containers, incubator, camera.

RESULTS: Neither Bacillus mycooides nor Escherichia coli developed during incubation, but a small portion of Bacillus subtilis developed on both missions. Fewer colonies developed inflight than in the controls, and those that developed were usually larger, grew faster, displayed gram strain variance and morphology change. Fungal contamination was reported. The inflight colonies exhibited more pronounced topography and were more sensitive to several antibiotics during postflight testing.

CONCLUSIONS: Real-time observation of bacterial growth has shown definite changes in behavior induced by growth in the Skylab environment. These changes may be either environmental or genetic in nature, or both. Work continues to better define these changes and to identify their causes.

PUBLICATIONS: 197, 377, 500

PRINCIPAL INVESTIGATOR(S): Gerald R. Taylor

EXPERIMENT TITLE/NUMBER: Medical Microbiological Analysis of U. S. Crewmembers

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Environmental health

OBJECTIVES: To identify and trace all microorganisms of potential medical importance.

PROTOCOL: Nine sets of specimens were collected from the three prime Apollo crewmembers on days F-45, F-30, F-15, and F-7, and on launch day; once during flight on recovery days R+0, R+15, and R+30. Inflight samples were obtained from all five flight crewmembers on both spacecraft. During each preflight and postflight sample period, microbial specimens were collected from 10 sampling sites on each crewmember. Calcium alginate swabs wetted in 0.3M phosphate buffer were used to sample each of the seven body surface areas. Dry calcium alginate swabs were used to sample the surfaces of the tonsils and the posterior pharyngeal vault before collection of the gargle specimen.

EQUIPMENT: Microbial sample collection device.

RESULTS: Although several potential pathogens were recovered from each of the flight and breakup crewmembers before and after flight, no disease events were reported. Candida albicans and Staphylococcus aureus were shown to have been transferred from one crewmember to another during flight.

CONCLUSIONS: There were no medically significant changes in the microbial population, nor were any long-term hazards noted.

PUBLICATIONS: 506, 507, 508

PRINCIPAL INVESTIGATOR(S): Gerald R. Taylor, Kathryn D. Kropp, Mary R. Henney, Suzanne S. Ekblad, Anwar A. Baky, Theron O. Groves, Thomas C. Molina, Jean G. Decelle, Carolyn F. Carmichael, Nina J. Gehring, E. Landrum Young, I. L. Shannon, William J. Frome, and N. R. Funderburk

EXPERIMENT TITLE/NUMBER: Microbial Exchange, AR-002

PROGRAM/MISSION: Apollo-Soyuz Test Project

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Environmental health

OBJECTIVES: To evaluate components of the infectious disease process in space flight by measuring alterations in the composition of the microbial populations inhabiting the crewmembers and spacecraft, the ability of each crewmember's defense mechanism to resist infection, and the ability of certain microorganisms to originate infections.

PROTOCOL: Sample specimens were collected from 10 sites on the Apollo and Soyuz crewmembers and from 15 areas on the inner surfaces of each spacecraft at specific times pre-, inflight, and postflight. Saliva and blood samples were also collected pre- and postflight. Analyses included dilution and plating of specimen materials, isolation of microbial colonies, and evaluation of growth properties on the initial isolation media.

EQUIPMENT: Microbial collection and storage device.

RESULTS: A variety of potential pathogens was recovered from each of the crewmembers pre- and postflight. However, no disease events were reported. Cardida albicans and Staphylococcus aureus were shown to be transferred from one crewmember to another during flight. No other medically significant changes were observed.

CONCLUSIONS. The proposed simplification of the population of medically important microorganisms and the theorized postflight microbial shock could not be supported by the results of this study.

PUBLICATIONS: 510, 511, 512

PRINCIPAL INVESTIGATOR(S): Gerald R. Taylor, Ronald T. Wrenn, Walter L. Ellis, Richard C. Simmonds, A. M. Heimpel, R. A. Long, B. G. Foster, D. O. Lovett, J. Spizizen, J. E. Isherwood, Horst Buecker, G. Horneck, H. Wollenhaupt, P. A. Volz, Y. C. Hsu, D. E. Jenger, J. L. Hiser, J. M. Veselenak, Eugene V. Benton, M. E. Parson, J. Vernon Bailey, Robert A. English, Bennie C. Wooley, and Charles E. Chassay

EXPERIMENT TITLE/NUMBER: Microbial Response to Space Environment

PROGRAM/MISSION: Apollo 16

CLASSIFICATION: Microorganism - (Bacillus thuringiensis, Aeromonas proteolytica, Bacillus subtilis, strains HA 101 (59), h. 101 (59)F, and 100, Escherichia coli T-7 phage, Chaetomium globosum, Trichophyton terrestre, Rhodotorula rubra, Saccharomyces cerevisiae)

DISCIPLINE(S): Radiobiology, Genetics, Cell biology

OBJECTIVES: To evaluate the effect of a particular space flight on the survival rate of different microbial species.

PROTOCOL: Each microbial sample containing 100 to 1 million live cells, was housed in chambers or cuvettes for flight and ground controls. Microbes could be suspended in 50ul of fluid or dried on a carrier, exposed to vacuum of space or retained at 1 atm. An optical filtering system controlled the total radiant energy reaching exposed test systems from a minimum of  $4 \times 10^6$  ergs/cm<sup>2</sup> to a maximum of  $8 \times 10^8$  ergs/cm<sup>2</sup>.

EQUIPMENT: Microbial ecology evaluation device (MEED) containing 796 cuvettes, 140 neutral density filters, 28 bandpass filters, 8 recording thermometers, one high-energy multicharged particle dosimeter, 64 potassium ferrioxalate actinometry cuvettes, 44 photographic film cuvettes, and 16 thermoluminescent dosimeter cuvettes.

RESULTS: Bacillus thuringiensis showed no change in survival rate after exposure to solar ultraviolet irradiation at 254, 260, 300 nm. Significant decrease in survival rate after exposure to full sunlight was observed but is not considered anomalous behavior.

Aeromonas proteolytica cells were evaluated for survival and quantitatively tested for alterations in toxin production. Postflight, there was no significant difference between the survival rates of inflight and ground controls.

The lethal effects of irradiation on Bacillus subtilis HA 101 (59) strains at peak wavelengths of 254 and 280 nm were greater for dried spores than those in water suspensions. The F strain was more sensitive at both wavelengths. Greater loss in viability was found when spores of Bacillus subtilis 168 were exposed to space vacuum and solar UV irradiation at 254 nm. No change in survival with vacuum alone was noted.

Escherichia coli T-7 bacteriophage was resistant to space vacuum. There was some sensitivity to solar UV irradiation at 254 nm. The dose response curve had the same shape as the ground controls.

Trichophyton terrestre and Saccharomyces cerevisiae showed an insignificant decrease in viability to solar UV irradiation. Chaetomium globosum and Rhodotorula rubra demonstrated no significant change in survival rate.

The results of the dosimetry experiments indicated that the optical filter components of the MEED performed in a manner which allowed critical evaluation of exposed biological test systems.

CONCLUSIONS: No statistically valid differences could be detected in the survival of flight samples when compared to corresponding ground controls. In general, these evaluations were based on multiple observations of from 10 to 30 replicates of up to one million cells each. While the results of this experiment conflict with those of certain other space flight investigations, it must be observed that the conditions of a particular space flight cannot be exactly duplicated, and therefore results from different flights are not directly comparable.

PUBLICATIONS: 36, 38, 39, 95, 123, 126, 130, 200, 201, 354, 476, 498, 499, 503, 504, 513, 514, 515, 543, 577

PRINCIPAL INVESTIGATOR(S): Gerald R. Taylor, Royce M. Brockett, James K. Ferguson, Richard C. Graves, and Bernard J. Mieszkuc

EXPERIMENT TITLE/NUMBER: Skylab Environmental and Crew Microbiology Studies

PROGRAM/MISSION: Skylab 2, 3, 4

CLASSIFICATION: Human, Microorganism

DISCIPLINE(S): Environmental health

OBJECTIVES: To detect the presence of potentially pathogenic microorganisms on the crewmembers and their spacecraft and to obtain data which would contribute to an understanding of the response of the crew's microbial flora to the space environment.

PROTOCOL: Microbial flora samples were collected from selected sites in Orbital Workshop, Command Module, on crew body surfaces and from urine and feces, preflight, inflight, and postflight.

EQUIPMENT: Calcium alginate swabs.

RESULTS: Approximately 10,000 microbial isolations were obtained, identified and characterized. Variation occurred in microbial response because of ecological relationships, host susceptibility and external environmental factors. Spread of pathogens between crewmen was common. While the total number of aerobes was found to increase, the species and number of anaerobes decreased.

CONCLUSIONS: Data showed that, while gross contamination of the Skylab environment was demonstrated and there were several inflight disease events, such events are not limiting hazards for long term manned space flights. Intercrew transfer of pathogens was demonstrated, although evidence of postflight microbial shock was not found.

PUBLICATIONS: 88, 517

PRINCIPAL INVESTIGATOR(S): R. C. von Borstel, R. H. Smith, Anna R. Whiting,  
and D. S. Grosch

EXPERIMENT TITLE/NUMBER: Mutational and Physiologic Responses of Habrobracon  
in Biosatellite II, P-1079

PROGRAM/MISSION: Biosatellite II

CLASSIFICATION: Animal, Microorganism - Parasitic wasp (habrobracon  
juglandis), Brine shrimp cysts (Artemia salina),  
Microorganism (Saccharomyces cerevisiae)

DISCIPLINE(S): Radiobiology, Genetics, Behavioral science

OBJECTIVES: To survey mature sperm and all different 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.

PROTOCOL: Male and female wasps were irradiated preflight, inflight, or not  
at all with <sup>85</sup>Sr at 4000 R, 2000 R, 1000 R, 500 R or 0 R. Thirty parameters  
of genetic, mutational, biochemical, behavioral, and physiological character  
were measured. Artemia salina cysts were used since they are sensitive to  
vibration. Saccharomyces cerevisiae were used to detect scattered radiation.

EQUIPMENT: Habrobracon flight containers, <sup>85</sup>Sr source, LiF powder, glass rod  
dosimeters.

RESULTS: Spaceflight effects were enhancement of fecundity and hatchability  
of primitive and transitional oonia, disorientation of male mating behavior,  
increased life span of females and decreased xanthine dehydrogenase activity  
in males. The effects of radiation were decreased hatchability and enhanced  
fecundity of eggs. The only mutagenic effect found was a threefold  
enhancement of the recessive lethal mutation frequency in the nonirradiated  
sperm in the orbited males. No difference was found in intragenic or  
intergenic recombination endpoints comparing flight and ground control  
Saccharomyces. The Artemia cysts were not influenced by spaceflight or gamma  
radiation received inflight.

CONCLUSIONS: The enhancement of spontaneous recessive lethal frequency in  
sperm was induced by some factor of the flight profile other than  
weightlessness. The excess of deaths found among the offspring from females  
flown might have been from a mixture of chromosome imbalance phenomena and  
recessive lethal mutations induced by the spaceflight conditions. The  
increased fertilizing capacity appeared to be an enhancing effect of radiation  
combined with weightlessness. The strong trend for enhanced emergence from  
Artemia cysts might have been caused by vibration.

PUBLICATIONS: 226, 227, 228, 229, 230, 545, 546, 547, 548, 549

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