

*Vol. 3*

*N-29*

*2060 013 333*

# **Spacelab Science Results Study**

## **Final Report**

### **Volume III, Microgravity Science**

Contract number  
NAS8-97095 Task No H-30194D

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August 18, 1999



# Spacelab Science Results Study

## Volume III: Microgravity Life Sciences

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### Introduction

The purpose of this Spacelab Science Results Study is to document the contributions made in each of the major research areas by giving a brief synopsis of the more significant experiments and an extensive list of the publications that were produced. We have also endeavored to show how these results impacted the existing body of knowledge, where they have spawned new fields, and, if appropriate, where the knowledge they produced has been applied.

The variety of disciplines that were accommodated by the Spacelab series of experiments logically group into 3 distinct categories; 1. External Observations in which the Shuttle/Spacelab is used as an observing platform, 2. Microgravity Sciences that make use of the microgravity environment to further the studies of Fluid Physics, Combustion Science, Materials Science, and Biotechnology, and 3. Life Sciences that studies the response and adaptability of living organisms to the microgravity environment. Because of the bulk of the material involved and the diverse interests, the report has been divided into three volumes with the previously mentioned titles.

The material used in study came from many sources including the Mission Summary Reports, Mission and/or Investigator Team WEB sites, the Life Science Data Archive, the International Distributed Experiments Archives (IDEA), various survey papers, conference proceedings, and the open literature publications of the Investigators. The International Distributed Experiment Archives contains both the NASA Microgravity Research Experiments (MICREX) database and the ESA Microgravity Database. We have identified 1251 publications from the Spacelab Life Science missions, of which 436 appeared in refereed journals.

We also wish to acknowledge the work of our student assistants; Ann Pierce, Gayla Pounders, and Olga Kostrova who spent many hours searching various data bases for reference material.

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**SPACELAB MISSIONS**  
**SCIENTIFIC ACHIEVEMENTS**  
**LIFE SCIENCES**  
**INTRODUCTION**

**A. OVERVIEW**

Life sciences experiments were flown on 17 of the 36 Spacelab missions between 1981 and 1998. More than 375 separate experiments were designed, developed, and conducted by more than 138 principal investigators and 536 co-investigators. Over a thousand publications and reports were published and results from more recent Spacelab missions, including Neurolab, are just beginning to appear in journals. This document describes the objectives, results and significance including the impact of the research on subsequent science and technology, facilities used, a narrative summary of most significant scientific findings, and a bibliography of publications resulting from Spacelab missions research. Information in this document was obtained from available sources predominantly NASA and ESA websites. The addresses for website source material is included in Appendix D.

Table 1 lists the missions on which life sciences experiments were flown. This table also includes mission duration which increased from a little over two days on STS-2 to almost 17 days on STS-78. The complexity of life sciences payloads evolved in parallel with increased time on orbit.

**Table 1. Spacelab Missions Which Included Life Sciences Experiments**

	Mission	Launch	Landing	Mission Duration			Payload Designation
				Days	Hours	Minutes	
1.	STS- 2	11/12/81	11/14/81	2	6	13	OSTA-1
2.	STS- 3	03/22/82	03/30/82	8	0	4	OSS-1
3.	STS-9	11/29/83	12/08/83	10	7	47	Spacelab 1
4.	51-B	04/29/85	05/06/85	7	0	8	Spacelab 3
5.	51-F	07/29/85	08/06/85	7	22	45	Spacelab 2
6.	61-A	10/30/85	11/06/85	7	0	44	Spacelab D-1
7.	STS-40	06/05/91	06/14/91	9	2	14	Spacelab SLS-1
8.	STS-42	01/22/92	01/30/92	8	1	14	IML-1
9.	STS-47	09/12/92	09/20/92	7	22	30	Spacelab J
10.	STS-55	04/26/93	05/06/93	9	23	39	Spacelab D-2
11.	STS-58	10/18/93	11/01/93	14	0	12	Spacelab SLS-2
12.	STS-65	07/08/94	07/23/94	14	17	55	IML-2
13.	STS-71	06/27/95	07/07/95	9	19	22	Spacelab Mir
14.	STS-73	10/20/95	11/05/95	15	21	53	USML 2
15.	STS-78	06/20/96	07/07/96	16	21	48	LMS
16.	STS-90	04/17/98	05/03/98	15	21	50	Neurolab

Life sciences experiments fall into three major discipline areas which are: 1) Advanced Human Support Technology, 2) Biomedical Research and Countermeasures, and 3) Gravitational Biology and Ecology. Table 2 shows the major disciplines and the several sub-disciplines under each of these categories.

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**Table 2. Life Sciences Discipline Categories**

<p><b>Advanced Human Support Technology and Ecology</b>          Advanced Environmental Monitoring          Advanced Life Support          Space Human Factors Engineering</p> <p><b>Biomedical Research and Countermeasures</b>          Prediction          Clinical Research          Countermeasures</p> <p><b>Biology</b>          Environmental Health          Physiology, Behavior and Performance          Radiation Health</p>	<p><b>Gravitational Biology</b>          Cell Biology          Developmental Biology          Evolutionary Biology          Molecular Biology          Global Monitoring and Disease</p> <p>Gravitational Ecology          Organismal and Comparative</p> <p>Molecular Structures, Physical Interacti          Plant Biology</p>
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For each of the Spacelab missions, the disciplines were further subdivided to describe the individual experiments. Table 3 lists experiment specific categories. Section II is a narrative summary of the most significant scientific findings from the Spacelab missions.

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**Table 3. Experiment Specific Categories**

<p>Animal Physiology          Biorhythms          Bone Physiology          Cardiovascular/Cardiopulmonary          Cell Proliferation and Differentiation          Clinical Medicine          Developmental Biology          Electrolyte physiology          Endocrinology          Genetics          Gravity Sensing          Hematology          Human Physiology          Immunology          Interdisciplinary physiology          Membrane Behavior</p>	<p>Metabolism and nutrition          Muscle physiology          Musculoskeletal          Neuromuscular and Sensory-motor          Neurophysiology          Neuroscience          Neurovestibular          Pharmacology          Plant Physiology          Pulmonary Physiology          Radiation Biology          Rat Bone Physiology          Rat Hematology          Regulatory Physiology          Renal Physiology</p>
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These experiments utilized a number of different facilities designed and adapted to provide maximum capability for the various experiments. The supporting facilities flown on the Spacelab missions are given in Appendix B.

The number of publications resulting from Spacelab research is shown in Table 4. Since data are still under analysis for the Spacelab mission experiments flown in the late 1990 timeframe, additional publications will be available over the next few years.

**Table 4: Number of Life Sciences Publications Resulting from Spacelab Experiments.**

Mission	Year	Journals	Other	Total
STS-2/OSTA-1	1981	1	0	1
STS-3/OSS-1	1982	5	1	6
STS-9/Spacelab 1	1983	59	18	77
STS-51F/Spacelab 2	1985	4	3	7
STS-51B/Spacelab 3	1985	74	78	152
STS-61A/Spacelab D-1	1985	36	52	88
STS-40/Spacelab Life Sciences 1	1991	44	35	79
STS-42/International Microgravity Laboratory 1	1992	38	40	78
STS-47/Spacelab J*	1992	79	489	568
STS-58/Spacelab Life Sciences 2	1993	36	25	61
STS-55/Spacelab D-2	1993	21	34	55
STS-65/International Microgravity Laboratory 2	1994	37	38	75
STS-71/Spacelab Mir	1995	Not Available	Not Available	Not Available
STS-73/United States Microgravity Laboratory 2	1995	Not Available	Not Available	Not Available
STS-78/Life and Microgravity Spacelab	1996	3	2	5
STS-90/Neurolab	1998	Not Available	Not Available	Not Available
Totals		436	815	1251

\* Total number of publications shown includes information from NASDA's report at the "Spacelab Accomplishments Forum", Washington, D.C. March 10-11, 1999. (Journal Articles: 62; Other Publications: 467). Not available: Not posted in website.

**Note:** In the text of Section II, references of principal investigators and mission refer to the tables in each section and not to published papers. In a few cases, reference is made to a paper and the full citations is given in the text. Papers published from the research of the Spacelab missions are included in the bibliography presented in Appendix C. These publications can be located from the names of investigators shown in the tables in the text of Section II.



## **SECTION II**

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### **SIGNIFICANT SCIENTIFIC RESULTS SUMMARIES**

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## **A. GRAVITATIONAL BIOLOGY AND ECOLOGY**

### **Significant Scientific Results Summary**

#### **1. CELL AND MOLECULAR BIOLOGY**

Cell and molecular biology investigations were conducted on eight of the 17 Spacelab missions which included Life Sciences experiments. They were flown under the Life Sciences discipline category "Gravitational Biology and Ecology". The experiment specific categories included cell growth and metabolism, organelles and structures, immunology, hematology, bacteria and viruses, yeast, circadian rhythm, and protoplasmic streaming. Experiment descriptions and publications resulting from the individual experiments in each category are given in Appendix A. The following summaries of the significant findings for each experiment category are a compilation extracted from available internet information and publications abstracts and are presented as an overview of experimental results.

In the interpretation of all cell biology experiments flown in space, it is important to understand that differences in growth, metabolism and function can reflect differences in hardware used as well as the particular characteristics of launch, payload location on the Shuttle, and other mission and experiment specific parameters including temperature changes during an experiment, length of the mission, starting and stopping of the 1g in-flight reference centrifuge during sampling, and storage of samples. Significant differences in response to spaceflight are also cell type and culture dependent. Not all cell types respond in the same way to conditions of spaceflight. For instance, human lymphocytes are shown to be 90% blunted in growth response in microgravity (Cogoli, A. et al., Cell sensitivity to gravity. *Science* 225: 228-230 (1984 )) yet other cell types, some of which are described below, appear to be unaffected by spaceflight and microgravity.

#### **Experiment Specific Category - CELL PROLIFERATION AND DIFFERENTIATION**

Investigations with single cells in culture flown on various microgravity-accessing launch vehicles have consistently shown that biological mechanisms such as proliferation, metabolism, and differentiation are altered as a result of spaceflight (Cogoli, A, et al., Gravity effects on single cells: Techniques, findings and theory. In: *Adv. in Space Biol. and Med.*, JAI Press Inc. 1, 183-248 (1991)). The Spacelab missions on which cell proliferation, differentiation and metabolism experiments were conducted are shown in the table below.

Experimental results from the **Hybridoma cells flown on Spacelab D-1** showed no clear effect of microgravity on cell proliferation, however, the number of cells in the flown cultures was slightly lower than corresponding 1g controls. Viability of the cells was 15% reduced compared to ground controls however, non-fixed flown cells resumed normal growth rate when cultured under normal conditions in the laboratory post-flight. Based on amino acid analysis, there was no significant difference in metabolism of flown cells, however, the biosynthesis of glycine and beta-alanine were increased by a factor of 1.4 in microgravity compared to 1g controls. Though not

large, these differences are important because they provide more evidence that cells alter metabolic processes during spaceflight.

Somewhat different results were found in the **Hybridoma cell** experiment flown on **IML-1**. The IML-1 experiment used Hybridoma cells of a sub-clone of the cell line 7E3-N which produces antibodies against lipopolysaccharide binding protein. These cells showed a significant increase in cell proliferation between the second and fourth day though a growth lag was evident and cells appeared to begin growing only after day 2 in microgravity. Analysis of metabolic data revealed that production of monoclonal antibodies; glucose and glutamine consumption; and secretion of lactate and ammonia on a per cell basis were lower in microgravity than in 1g. These data show that microgravity has a significant effect on metabolism of cells. Production of monoclonal antibodies commercially in space does not seem to be advantageous based on this experiment.

### SINGLE CELLS IN CULTURE

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Cell Type	Principal Investigator
Spacelab D-1	61-A	1985	7+	Hybridoma cells	Bouteille, M.
IML-1	STS-42	1992	8+	Hybridoma cells Virus transformed cells Hamster kidney cells/beads	Cogoli, A. Cogoli, A. Cogoli, A.
Spacelab -J	STS-47	1992	7+	Monkey kidney (JTC-12)	Aato, A.
Spacelab D-2	STS-55	1993	9+	Human dermal fibroblasts	Mueller, P.K.
USML-2	STS-73	1995	15+	SF9 Insect cells	Johnson, T.

**Murine Friend Leukemia Virus transformed cells** were flown on **IML-1** to investigate proliferation and differentiation in microgravity. These cells are used as a model for murine erythropoiesis since they differentiate in the presence of dimethylsulfoxide toward erythroid lines. Results for all parameters tested, showed no significant differences in microgravity and the 1g in-flight control and ground responses. There was a slight but not significant increase in cell growth in flown cells after 140 hours of incubation. The amount of hemoglobin produced was the same in flight and ground controls. Cell morphology and mitotic index showed no significant changes between flight and ground controls. Thus Friend cells do not appear to change their behavior in microgravity. These results are extremely significant because they illustrate clearly by the parameters measured (growth, metabolism and differentiation), that not all single cell types are affected by spaceflight and microgravity.

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**Hamster kidney cells** (ATCC CCI 15) grown on Cytodex 3 microcarrier beads were flown on IML-1 to evaluate a dynamic cell culture system (DCCS) and to investigate the behavior of anchorage-dependent hamster kidney cells on the beads with respect to proliferation, production of tissue plasminogen activator (t-PA), and cell metabolism in microgravity. Results showed that microgravity had no effect on cell growth and metabolism of the hamster kidney cells. Data on pH, glucose and lactate concentration showed that the DCCS functioned adequately and the cells consumed almost all of the available glucose. Production of t-PA was similar in all cultures and no significant differences among cultures was seen for ammonia and glutamine confirming that metabolic processes did not appear to be affected in microgravity in these cells.

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On SL-J a very significant experiment using **monkey kidney derived cultured cells** (JTC-12) was flown to evaluate the rearrangement of the cytoskeleton to gain understanding of the direct effects of microgravity on the cytoskeleton and cell structure and proliferation. Results showed no differences between flight and ground control cells in early culture in microgravity. Proliferation, glucose use and urokinase secretion were similar in cells returned alive and cultured postflight. The cells from flight had decreased numbers in the S phase and increased numbers in the G2M phase of the cell cycle indicating a possible spaceflight- or microgravity-related cell cycle block, not in G1 as is usual for aging cultures, but in G2M. This is usually indicative of some perturbation or stress. Perhaps the most significant finding was that electron microscopy of cells fixed in microgravity showed little bundle rearrangements of microfilaments at the cell margin. Morphologically, this was significantly different from ground controls and provides additional evidence of cytoskeletal/membrane interface perturbation induced by spaceflight.

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**Human dermal fibroblasts** were flown on the **Spacelab D-2 Mission** to evaluate biosynthesis of collagen to gain understanding of bone mass loss during spaceflight. These cells were chosen because they are easily isolated and maintained in culture and the collagen biosynthetic profile is similar to that of bone forming cells. The most significant results showed that the cells remained attached to coverslips, thus were alive, and all cultures synthesized collagen I, III and V. Quantitative analysis showed a 40% increase, compared to 1g controls, in collagen synthesis in microgravity. Another very significant finding was that hypergravity at 1.44g, 6.6g, and 10g decreased collagen synthesis. At 10g, collagen synthesis was reduced 85% compared to 1g. Relative proportion of collagen from total protein synthesized, the secretion of collagen from the cells, proline hydroxylation of individual collagen alpha-chains, and the relative proportion of collagens I, III, and V synthesized were not adversely affected by spaceflight. These data show that the collagen biosynthetic process is not affected (in these cells) by microgravity and imply that some factor other than collagen synthesis is responsible for bone mass loss in space.

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**Control of Proliferation arrest and release** is extremely important to spaceflight research since the cells in the flight hardware must be turned over for installation into the Shuttle approximately 24 hours prior to liftoff. Johnson, et al. have developed a factor, CeReS-18, that causes cell cycle arrest in cultured insect cells. Dilution by addition of culture medium releases cells from arrest. The usefulness of this factor in microgravity research was demonstrated on USML-2. This significant finding has potential for stabilizing cultures for future microgravity missions.

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**Experiment Specific Category: IMMUNOLOGY - CULTURED CELLS**

Cell mediated immunological response in the body is achieved by the T lymphocytes (T cells) of the immune system. T cells are activated and increase in number in response to stimulation by antigen presenting cells as a defense against infection by organisms such as bacteria, fungi, and viruses. In the laboratory T cell activation response can be elicited by use of Concanavalin A (Con-A), a mitogen derived from plants that acts as an antigen to stimulate growth and function of T lymphocytes. T cells in blood drawn from Astronauts and Cosmonauts during the early spaceflight missions showed a significantly blunted response to mitogenic challenge which persisted for up to seven days after the flight. Twelve cell immunology-related experiments were flown on seven of the Spacelab missions as shown in the table below.

**IMMUNOLOGY**

<b>Spacelab Designation</b>	<b>STS Mission</b>	<b>Year</b>	<b>Duration (days)</b>	<b>Cell Type</b>	<b>Principal Investigator</b>
Spacelab 1	STS-9	1983	10+	Human lymphocytes	Cogoli, A.
Spacelab D-1	61-A	1985	7+	Lymphocyte activation (ex-vivo) Lymphocyte activation (in-vitro)	Cogoli, A. Cogoli, A.
SLS-1	STS-40	1991	9+	Lymphocyte proliferation (beads) Lymphocyte proliferation (IL-1,2)	Cogoli, A. Cogoli, A.
IML-1	STS-42	1992	8+		Cogoli, A.
Spacelab D-2	STS-55	1993	9+	Growth of lymphocytes Activation of lymphocytes	Reske, K. Reske, K.
IML-2	STS-65	1994	14+	Lymphocyte movement Lymphocyte proliferation Lymphocyte activation Cytokines	Cogoli, A. Cogoli, A. Cogoli, A. Schmitt, D. A.

A landmark experiment was conducted by **Cogoli et al.** on the **Spacelab 1** Mission flown on STS-9 in 1983. This experiment has led to increasingly sophisticated research by a number of investigators over the past 16 years, yet without discovery of the causative mechanism(s) for reduced lymphocyte growth in microgravity. The experiment on Spacelab 1 was the first to show a dramatic, quantitative response to spaceflight at the single cell level. The objective of the experiment was to establish whether functional changes occurred in cells of the immune system and to investigate whether single cells are sensitive to gravitational changes. Normal **peripheral human T lymphocytes** were growth stimulated in flight by addition of Con-A. In microgravity,

activation of the cells was 90% less than that of the ground controls (Cogoli, A et al. Cell sensitivity to gravity. Science 225: 228-230 (1984)). The experiment was repeated on D-1 and an in-flight 1g centrifuge was included as a control in addition to the ground controls. Again activation response was reduced by 90% in microgravity compared to ground. However, the response of cells in the 1g centrifuge was intermediate between microgravity and the ground control indicating a gravity-sensitive mechanism in lymphocyte response. Cosmic radiation was ruled out as a factor since cells in the 1g in-flight centrifuge, which may shield radiation, appeared normal. The most significant result of the D-1 mission was the confirmation of the SL-1 results that showed 90% blunted growth response of T lymphocytes in microgravity.

A second experiment flown by Cogoli et al. on D-1 used **whole blood** drawn from Astronauts to study role of spaceflight stress on the immune system. Whole blood, drawn before, during, and after the mission was cultured in presence of Con-A. The most significant finding was the confirmation of earlier results showing blunted T cell response to mitogenic challenge during and for up to seven days post-flight suggesting that physical and psychological stress during space flight depresses the human immune system. Additionally, the experiment again confirmed Cogoli's SL-1 results.

To gain further information on the mechanisms causing reduced lymphocyte response during spaceflight, Cogoli et al. flew **two experiments** on SLS-1. The mechanisms involved in T cell activation are very complex and require sequential expression of a number of genes coding for specific factors in the signal transduction cascade. Cell-cell interaction is necessary and antigen presenting cells (macrophages) must come into contact with the resting T cells in order to stimulate the T cell activation cascade. In the experiments flown on SLS-1, Cogoli mixed microcarrier beads with the cells as a way to increase cell contact interactions. The results were surprising. Although lymphocytes do not normally attach to substrata, the cells attached to the microcarriers and activation in microgravity, in response to Con-A, was now double that of ground controls. The cells without microcarrier beads again failed to respond to Con-A thus confirming the SL-1 and D-1 results. In addition, in the presence of microcarriers the secreted signaling factors, IL-1, IL-2 and interferon-gamma were significantly increased in microgravity compared to cultures with no beads. After 46 hours in microgravity, IL-2 increased by more than 400% in bead cultures compared to cultures without beads. Cogoli's conclusions from these results suggested that depression of *in vitro* activation of suspended lymphocytes during spaceflight may be due to failure of monocytes acting as accessory cells since secretion of IL-1 was significantly inhibited in microgravity. Based on the two experiments flown on SLS-1 Cogoli concluded that in microgravity: 1) IL-2 is produced independently of IL-1, 2) IL-1 production is triggered only when monocytes adhere to microcarriers, 3) the expression of IL-2 receptors depends on IL-1 and 4) if sufficient IL-1 is present, activation is enhanced in microgravity. These conclusions were challenged by later experiments on IML-2.

On IML-2 Cogoli, et al. again tested response of peripheral lymphocytes to Con-A challenge. This time the relative concentrations of the mixed population of lymphocytes was evaluated pre-flight. The population contained 82.5% lymphocytes and 6.5% monocytes with granulocytes comprising 11%. Again mitogenic activation was significantly reduced (80%) in microgravity compared to ground. In the in-flight 1g centrifuge control, activation was reduced by 50% of

ground. (It should be noted that the 1g was not maintained completely because of an early but corrected centrifuge malfunction and start/stops of the centrifuge to remove samples at appointed times). Addition of exogenous IL-1 and IL-2 alone or in combination did not increase the activation in microgravity but did slightly increase secretion of interferon-gamma. In this experiment the secretion of IL-1 by monocytes was not inhibited therefore, the failure of lymphocytes to grow in microgravity is not due to faulty secretion of IL-1 by the monocytes but to some other factor, perhaps involving the IL-2 receptor.

In a **second experiment on IML-2**, **Cogoli et al.** used the NIZEMI microscope system and the same lymphocyte preparation as described above to visualize the motion and interactions of human lymphocytes in suspension in the presence of Con-A in microgravity. This experiment was designed to answer the question of whether inadequate cell-cell interaction is a reason for blunted lymphocyte activation in microgravity. Cell-cell interactions were visualized from video tapes made at selected times after addition of Con-A to the cells. The tapes clearly showed that the cells are capable of autonomous motion in random directions. In fact, the mean velocity of cells in microgravity was significantly higher than at 1g. In addition they formed aggregates which grew in size with time in microgravity. This effectively disproved the formerly held theory that lack of cell-cell interaction is the reason for blunted lymphocyte response in microgravity. Both in flight and ground cultures, the aggregates changed size and shape throughout the observation periods. Individual cells also changed their shape, from round to elongated and vice-versa. Movements consisted of rocking and twisting and single cells changed location and migrated in and out of aggregates. These observations are extremely significant and prove that cell-cell interactions, necessary for lymphocyte activation, absolutely do occur in microgravity and that lack of activation is not because of failure of cells to interact. So, the nil activation of human lymphocytes in microgravity remains a mystery. A clue from these extremely important Spacelab investigations is that lymphocytes are not progressing through the cell cycle resulting in the dramatically decreased activation and growth.

Using Balb/c cells cultured in the presence of an antigen and lymph node cultures of mixed T and B cells, **Cogoli et al.** showed on **IML-2** that antigen recognition and subsequent proliferation in microgravity is 3% to 24 % that of ground controls depending on cell type. The first step in T-cell recognition of antigen appears to be significantly compromised in microgravity.

Two experiments were conducted by **Reske et al.** on the **Spacelab D-2** mission which further clarified potential mechanisms causing blunted activation and secretory function of lymphocytes. In the normal activation of T cells, antigen presenting cells must contact resting T cells. This requires close contact between accessor and responder T cells. In Reske's approach, two cell types; ovalbumin (Ova)-specific T-responder cells (3DO-54.8) and second, accessor cells A20.2J (investigators nomenclature) were mixed. The objective of the experiment was to investigate accessor cell and responder T helper cell interactions. The most significant results were that the cells in this mixed culture grew as well in microgravity as in the 1g in-flight and ground controls. The objective of Reske's second experiment on D-2 was to measure cytokine secretion in the mixed cell cultures. The most important findings were that very small amounts of IL-1 and no IL-3 were secreted by the T-responder cells in microgravity whereas, cells in the ground controls and the in-flight 1g centrifuge control secreted comparable amounts of IL-2 and IL-3. The most

significant finding, discovered by evaluation of the RNA extracted from the co-cultures, showed that the level of lymphokine transcripts did increase in microgravity, however; the cells did not secrete these cytokines. Although the cells may be competent to synthesize these cytokines, some mechanism prevents secretion into the culture medium. The microcarrier beads appeared to facilitate secretion of IL-1 by the monocytes in Cogoli's experiments which then led to the observed two-fold increase in activation of the lymphocytes. The reason for increased secretion of cytokines in the presence of microcarrier beads in microgravity has not been clarified.

**Schmitt et al.** conducted an experiment on **IML-2** aimed at determining how microgravity affects the amount and subcellular distribution of PKC, an important factor in the early events of the T cell signal transduction cascade. In this case, Jurkat cells, a T lymphoblastoid cell line and U 937, a monocyte-like cell line were flown. Both of these are human leukemic origin, continuous cell lines. Results showed that distribution of PKC in these cells was significantly different from ground controls indicating a gravity-related effect on distribution of this critical intracellular signaling enzyme. In contrast to Reske's findings with co-cultured cells, IL-1 $\beta$  in cellular fractions was reduced by 30% in microgravity exposed cells compared to the 1g on board controls. This confirms that a microgravity- and cell type-related response is involved in IL-1 metabolism.

In summary, these Spacelab experiments have demonstrated that cell-cell contacts, necessary for T cell activation, do occur in microgravity and IL-1 secretion and synthesis may be involved though IL-1 release is not impaired in the presence of microcarrier beads or accessor/responder cell co-cultures. Addition of microcarrier beads promotes activation two-fold higher than ground controls yet without beads, lymphocyte activation in microgravity is almost totally abolished. Reasons for this are not clear. Signal transduction involving PKC appears to be altered in microgravity. Mechanisms remain an enigma yet very significant progress has been made as a result of the Spacelab missions. The impact to crew health on long term missions because of impaired cell mediated immunity is not known and remains a significant biomedical area to be investigated. Ongoing research is needed to investigate regulatory gene expression and signal transduction pathways as well as the role of apoptosis and cell cycle progression in order understand why lymphocytes do not grow in microgravity.

## **BACTERIA, YEASTS AND OTHER ORGANISMS**

Previous studies on U.S. biosatellites and Soviet Salyut missions showed an increase in bacterial growth rate (Kordium, V.A. et al., Nankove Dunka Publishers, Kiev. pp. 64-68, 1978 and, R.H., et al. NASA SP-104: 304-324, 1971). The experiments conducted on Spacelab D-1, D-2, IML-1, and USML-1 confirmed that the growth rate in bacteria as well as some other organisms is increased. In addition, antibiotic sensitivity is reduced and genetic transfer between bacterial cells is different in microgravity compared to ground controls. The table below shows the Spacelab missions on which these investigations were conducted.

In addition to increased growth rate, *Bacillus subtilis* flown on **D-1** showed reduced sporulation in microgravity. This was postulated to be due to the rapid growth and high population density depletion of nutrients and cell death before sporulation could occur (**Mennigmann et al.**). Later



on IML-1, sporulation occurred in microgravity at high frequency thus demonstrating that under proper conditions bacteria are able to form spores in space. Using shielded hardware on these Spacelab missions, these experiments showed that effects were due to microgravity and not cosmic radiation. On USML-2, Klaus further investigated the mechanism of increased bacterial growth in microgravity. He found that the kinetics of the growth curve in *E. coli* is changed. The lag phase time is decreased, growth phase is increased and there are more cells at the end of log growth going into the stationary phase.

## BACTERIA, YEAST, AND OTHER ORGANISMS

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
Spacelab D-1	61-A	1985	7+	Growth and differentiation Antibacterial activity Genetic recombination Circadian rhythm (algae) Protoplasmic streaming	Mennigmann, H Tixador, L. Ciferri, O. Mergenhausen Sobick, V.
IML-1	STS-42	1992	8+	Antibiotic activity Growth and sproulation Yeast chromosomes Paramecium Tetaurelia Protoplasmic streaming	Tixador, L. Mennigmann, H. Bruschi, C.V. Planel, H Block, I.
Spacelab D-2	STS-55	1993	9+	Growth and sproulation Yeast metabolism	Mennigmann, H. Donhauser, D.
IML-2			14+	Microenvironment Yeast growth (bioreactor) Protoplasmic streaming Gravitaxis ( <i>Loxodes</i> )	Bouloc, P. Cogoli, A Block, I Hemmersbach, R.
USML-2	STS-73	1995	15+	Growth and development	Klaus, D.

Physical properties including reduced convection and altered surface tension in microgravity may affect the microenvironment of cells. This in turn could influence the interaction of the cell membrane with this environment and alter the position of receptors on the membrane surface. On IML-2 Bouloc conducted an experiment to evaluate influence of the microenvironment on growth and membrane signal transduction in motile and non-motile strains of *E. coli*. The motile strain showed no significant differences in growth between flight and ground cultures. Conversely, the lag phase of the non-motile strain was shorter than ground controls. This is in agreement with the reduced lag phase in growth curve kinetics on USML-2 reported by Klaus. Interestingly, the lag phase in Bouloc's experiment was also shorter in non-motile bacteria

maintained in the 1g centrifuge in flight which suggests that some factor other than gravity may influence bacterial growth during spaceflight. Cosmic radiation may be ruled out since the cells were shielded in the 1g in-flight centrifuge in IML-2. Signal transduction in *E. coli*, measured by analysis of expression of an osmotic shock response gene, showed that the system transducing osmotic information from external medium to the cytoplasm is functional in microgravity.

**Transfer of genetic material** from one bacterium to another can occur by three means. One is conjugation in which ordered transfer of a portion of a chromosome occurs through a conjugation bridge formed between the donor and recipient cells. On D-1 conjugation in *E. coli* was enhanced by 40% in microgravity compared to ground controls (Ciferri et al.). The number of conjugation pairs was the same in space and ground, thus the increase in transfer is hypothesized to be the result of the low-shear environment of space allowing stability of bridges and uninterrupted transfer of the chromosome. A second gene transfer mechanism, transduction, achieves genetic transfer between bacteria via bacteriophages and the third genetic transfer mechanism is transformation or transfer of genes from one bacterium to another by plasmids. There was no difference in genetic material transfer between flight and ground by these two mechanisms.

**Altered sensitivity of bacteria to antibiotics** in microgravity was shown on D-1 and IML-1 (Tixador et al.). The minimum inhibitory concentration of antibiotics was increased two to four fold in microgravity compared to ground controls. Three possible explanations may account for this. One is that bacteria proliferate more rapidly, achieve higher biomass, thus a higher concentration of antibiotic is needed. Second is that transport of antibiotics into the cells may be altered in microgravity due to modification of membrane permeability. The third is that both of the above may operate together. The experiment of Tixador et al. on IML-1 showed shorter doubling times and earlier entry into the stationary phase for bacterial populations in flight compared to ground. No differences were shown by electron microscopy in the ultrastructures between flight and ground cells and the cellular envelopes had the same thickness. In the presence of antibiotic, the lag phase was increased and the growth rate was decreased. The doubling time in flight was shorter than ground even in presence of the antibiotic. These results suggest that the increased growth rate, not permeability of the cells, is the primary reason for reduced response of bacterial populations to antibiotics during spaceflight.

**Yeast** An objective of an experiment of Donhauser with strains of yeast (*Saccharomyces cerevisiae*) flown on the D-2 mission was to investigate modification of brewing yeasts for improvement of growth, efficiency of fermentation, fermentation by-products, and beer quality. Fermentation experiments were carried out with total populations and also with selected clones. Results showed that in some cultures faster fermentation, higher ester content or better beer quality was achieved in microgravity compared to ground controls. However, insufficient head retention and reduced fermentation rates were also observed indicating need for careful control of these processes if genetic engineering of better beer is to be achieved from microgravity process. In addition to the fermentation data, this experiment also yielded information on the genetics of the yeasts. The karyotypes of the total yeast populations remained stable during the mission. Data from the cloned cultures grown in microgravity displayed four different karyotypes yet no mutations were found in ground controls. Two experiments to evaluate chromosome behavior in yeast were also conducted on IML-1 (Bruschi et al.). The objectives were to evaluate cell yield, survival, and ability to

undergo meiosis, and to monitor mitotic chromosome segregation and recombination in space flown yeasts. There were no changes in total cell yield or survival in either experiment and yeast populations can be cultured in microgravity. The most significant finding was the recovery of intergenic mitotic recombinants in flown cell populations. The data show that mitotic recombinations were significantly more frequent than meiotic chromosome segregation.

In an experiment flown on IML-2, Cogoli et al. evaluated performance of a miniaturized bioreactor designed to study effects of prolonged space flight on continuous cultures of single cells. They were successful in qualifying the bioreactor and additionally the experiment provided significant information on growth and cell cycle of yeast (*Saccharomyces cerevisiae*). No remarkable differences were found in cell cycle, proliferation, cell volume, ethanol production or glucose consumption and no morphological anomalies were found. Both flight and ground cultures in the bioreactors showed presence of budding scars although bud scar frequency was significantly higher in flight samples (17%) than in ground controls (5%).

**Paramecium tetaurelia** has been shown in experiments previous to **Spacelab D-1** to increase growth rate and cell volume significantly and decrease cell dry weight and protein content (Planel H. et al., Spaceflight effects on *Paramecium tetaurelia* flown aboard Salyut 6 in the Cytos I and Cytos M experiments. *Adv. Space Res.* 1: 95-100 (1981). Whether these effects were due to microgravity or cosmic radiation could not be determined on the early flights. The experiment flown on **Spacelab D-1**, was designed to use the in-flight 1g reference centrifuge which can shield the organism from cosmic radiation allowing separation of microgravity and radiation effects. In agreement with previous results, the experiment on **Spacelab D-1** showed significantly higher growth rate in microgravity. A comparison of data from microgravity and the 1g in-flight centrifuge demonstrate that effects on *Paramecium* growth and volume in space are due to the effect of microgravity and not to cosmic radiation.

Two species of ciliates **Paramecium** and **Loxodes**, were flown on **IML-2** to evaluate gravitaxis, or swimming against gravity. These ciliates both use gravity as a cue for spatial orientation (gravitaxis) and to control their swimming velocity. *Paramecium* exhibits fast responses and has a swimming sensory cell and *Loxodes* senses accelerations via statocyst-like organelles. The objective of this experiment was to determine the gravity threshold for gravitaxis in microgravity by adding back g forces (slow rotating centrifuge-microscope, NIZEMI). Evaluation of response was measured using computer controlled image analysis of swimming tracks of the two ciliates. Results showed that the threshold for gravitaxis of *Paramecium* is below 0.3g and above 0.16g. For *Loxodes* the experiment did not yield threshold data however, prolonged cultivation in space did not change size and content of the barium sulfate granules (statoliths) in the statocyst-like organelles of *Loxodes*.

Another experiment on **IML-2** evaluated gravitaxis of the slime mold **Physarum polycephalum** (a multinucleated [plasmodial], acellular slime mold, Myxomycete) using the NIZEMI centrifuge microscope and video recorder. *Physarum* changes the rhythm of its periodic contractions and dilatations when subjected to accelerational variations. Reaction to gravitational stimuli in this organism was shown on D-1 and IML-1. On IML-2 the threshold for gravitaxis, or acceleration sensitivity was shown to be 0.1g. Results suggested that very small acceleration above this

threshold induced a complete response process. These experiments showed that the ability of the slime mold cells to respond to acceleration changes and proves that gravity response in *Physarum* is based on the direct effect of gravity. Direct effect is due to density differences within the cell and relayed via primary gravity receptors. The very low acceleration sensitivity indicates that the gravity receptors should be rather large and dense cell organelles. They must be more dense than the rest of the cell. Though the specific gravity receptor has not yet been identified, in *Physarum*, candidates are the numerous nuclei and/or very numerous mitochondria. Both of these organelles acting in concert could serve as an effective gravity sensing system.

Two experiments were conducted to evaluate the **streaming potential of slime mold** (*Physarum Polycephalum*), one on Spacelab **D-1** and the other on **IML-1**. One of the biophysical questions posed by scientists is whether the streaming potential of protoplasm could be changed in the absence of gravity. The giant cell of *Physarum polycephalum* has millions of nuclei, thus it is considered to be a plasmodium, and the plasmodium has numerous protoplasmic tubes containing fluid protoplasm. A system of contractile proteins generates rhythmic contractions and relaxations of the tubes. The contractions can easily be measured. Results from the **D-1** experiment showed highly regulated contraction-relaxation cycles in microgravity. This was considered to be an adaptational reaction of the organism to weightlessness. A very significant finding was the general gravisensitivity in a cellular organism that has no specialized structure to perceive gravity. To better understand whether a cell without a specialized structure for gravity perception can perceive and process gravistimuli, *Physarum* was flown again on **IML-1**. Results confirmed those of the **D-1** experiment by implying the existence of a gravireceptor but without unequivocal identification of a definitive structure or organelle in the cell.

**Two different strains of the unicellular green algae, *Chlamydomonas reinhardtii*, were used on D-1 to evaluate circadian rhythm.** Photoaccumulation served as a measure of responsiveness of circadian rhythm. Many organisms have a periodicity of 24 hours but on Earth it is not possible to discriminate between an internal biological clock and a circadian rhythm based on normal terrestrial rotation. Although there were some differences in amplitude, the results of this study showed that in microgravity the circadian rhythms of *Chlamydomonas* did not differ significantly from ground control experiments thus this organism appears to have an endogenous biological clock. Cell proliferation and survival rates in microgravity were higher and no mutations were found in flown samples.

# GRAVITATIONAL BIOLOGY AND ECOLOGY

## Significant Scientific Results Summary

### 2. DEVELOPMENTAL BIOLOGY

Developmental biology experiments were flown on eight Spacelab missions. A total of 24 experiments were conducted and seven different species were studied including insects, brine shrimp, jellyfish, amphibians (frogs and newts), fish mouse, and quail. The table below shows missions on which these experiments were flown.

#### Experiment Specific Category - DEVELOPMENTAL BIOLOGY

Several experiments were flown to evaluate the effects of the microgravity environment on development of insects. Effects of spaceflight on the development of *Drosophila melanogaster* were successfully evaluated on Spacelab D-1, IML-1 and IML-2. The significant findings from the D-1 experiment showed that embryos develop in space but with some variations in timing of the developmental process. IML-1 experiments essentially repeated the D-1 experiment and results showing early embryonic development under conditions of microgravity and the in-flight 1g centrifuge and ground controls are summarized as follows: 1) Oocyte production was significantly increased in microgravity compared to the 1g in-flight centrifuge and ground controls. 2) Embryos continuously exposed to microgravity were larger than controls. 3) Larvae showed thoracic and/or head abnormalities in the microgravity samples. 4) The lifespan of adult males continuously exposed to microgravity was shortened (75% that of controls), while life span of females was unaffected. On IML-2, the influence of microgravity on different developmental stages of *Drosophila* were further investigated to confirm previous conclusions and to evaluate whether mitochondrial metabolism may be involved in aging. Again the IML-2 experiment confirmed that *Drosophila* can develop in microgravity through all developmental stages. Additionally, delayed hatching and slower development in microgravity were again shown. Post-flight, all embryos, larvae, pupae and imagoes recovered and had normal morphology and function, however; males showed an accelerated aging response in terms of vitality assays (mating and negative geotaxis) as well as life-span and survival differences. In fact, flown males died significantly earlier than non-flown males. In-flight video of the behavior of the flies showed that young males exhibited markedly increased locomotor activity in microgravity compared to ground and most of the males in flight were continuously moving. In contrast to male life-span data, the females did not age more rapidly than ground controls yet females also showed increased locomotor activity in microgravity. Flies maintained on the 1g in-flight centrifuge had life-spans similar to those maintained in the centrifuge on the ground suggesting that microgravity may increase aging rate in *Drosophila*. Evaluation of mitochondrial 16S ribosomal RNA showed that microgravity-exposed flies had decreased 16S RNA compared to ground controls. This provides evidence that mitochondrial metabolism may be different in microgravity and could play a role in early aging. In general, a significant overall conclusion from these experiments is that in the absence of gravity, the developmental parameters most dependent on gravity were identified.

These experiments with *Drosophila* have significantly advanced our understanding of the influence of gravity on morphogenetic development in embryos.

## DEVELOPMENTAL BIOLOGY EXPERIMENTS

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Species Studied	Principal Investigator
Spacelab D-1	61-A	1985	7+	<i>Crasus morosus</i> <i>Drosophila</i> <i>Xenopus</i>	Buecker, H. Marco, M Neubert, J.
IML-1	STS-42	1992	8+	Brine shrimp <i>Drosophila</i> <i>Xenopus</i> Mouse long bone	Paulsen, A. Marco, R. Ubbels, G. Veldhuijzen, J.
SLS-1	STS-40	1991	9+	<i>Aurelia</i> differentiation	Spangenberg, D.
SL-J	STS-47	1992	7+	<i>Xenopus</i> Chick	Souza, K. Suda, T.
Spacelab D-2	STS-55	1993	9+	<i>Xenopus</i> and fish <i>Xenopus</i> and fish <i>Xenopus</i> and fish	Neubert, J. Horn, E. Rahmann, H.
IML-2	STS-65	1994	14+	<i>Aurelia</i> development Japanese red-bellied newt <i>Drosophila</i> Sea Urchin <i>Xenopus</i>	Spangenberg, D. Wiederhold, M. Marco, R. Marthy, H.J. Ubbels, G.A.
USML-2	STS-73	1995	15+	Pre-metatarsals (mouse)	Klement, B.
Spacelab Mir	STS-71	1995	9+	Avian blood vessel (quail) Afferent innervation (quail) Vestibular dev. (quail) Life cycle (quail) Contractile protein (quail) Eye development (quail) Skeletal develop. (quail) Visuo-vestibular (quail) Fecundity (quail)	Lelkes, P. I. Fermin, C.D. Fritzsch, B. Hester, P.Y. Anderson, P. Conrad, G.W. Doty, S. Shimiqu, T. Wentworth, B.

Progressing from insects to higher animals, the effects of microgravity on development of ephyrae from polyps of *Aurelia aurita* (Jellyfish) and the development of graviceptors of the ephyrae, formation or demineralization of statoliths and swimming/pulsing behavior were evaluated on

**IML-2 and SLS-1.** The most significant findings from these two experiments showed that the number of ephyrae formed per polyp were slightly higher in flown groups at eight hours after launch compared to pre-launch values. Perhaps the most significant finding was the ability of the jellyfish in microgravity to synthesize jellyfish-thyroxin (Jf-T4) which is required for ephyra production. There was no difference in morphology between space and ground developed ephyrae but abnormalities were found in pulsing behavior. This suggests an abnormal development of graviceptors or the neuromuscular system or a defect in the integration of impulses between the systems.

**Sea urchin larvae (*Sphaerechinus granularis*)** were flown on **IML-2** to determine whether mineralization and formation of skeletal structure occur properly and if larvae with skeletons already developed on the ground would lose mineral in microgravity. Sea urchin larvae in two developmental stages were flown. To determine if already formed skeletons de-mineralize in microgravity, larvae in the pluteus stage with internal skeleton already formed were chosen. This stage is characterized by a transient calcareous structure composed of calcium carbonate crystallized as calcite and a small amount of magnesium and organic matrix. To test whether larvae could mineralize a skeleton in microgravity, embryos in the blastula stage in which the skeleton is not yet formed were chosen. Significant results were that larvae developed skeleton in flight and no pronounced loss of mineral from already formed skeletons occurred. However, the skeletons that were formed showed some unusual architecture indicating that the process of association and positioning of the cells which determine the size and shape of the skeleton are particularly sensitive to environmental perturbations. Evaluation of calcium and magnesium did not show significant differences between flight and ground samples.

Five of the Spacelab missions, **D-1, D-2, IML-1, IML-2 and SL-J**, included investigations into the role of gravity and weightlessness on developing amphibian eggs. These experiments used eggs of *Xenopus laevis* (African three-clawed frog) to determine if fertilization occurs in microgravity and if embryo development is initiated. The most significant results, discovered on **IML-1**, showed for the first time that fertilization of a vertebrate egg can occur in microgravity and that embryos develop bilateral symmetry after sperm penetration. This implies that gravity is not required for establishment of normal dorso-ventral axis in *Xenopus*. The experiment flown on **SL-J** further characterized amphibian development by showing that embryos in microgravity progressed through gastrulae, and neurula stages and formed normal tadpoles. Finally, the experiment conducted on **IML-2** confirmed previous findings and added further information on development. Results from these Spacelab missions may be summarized as follows. *Xenopus* eggs, fertilized and developed in microgravity, form normal axis and neural plates and the tadpoles develop normally. Cortical rotation and cytoplasmic rearrangements that occur in normal development are not gravity dependent. Formation of the blastocoel is altered in microgravity. These anomalies do not interfere with mesoderm induction and development however, and from about the 9th stage forward the embryos recover and develop normally into normal tadpoles.

A series of experiments with *Xenopus*, cichlid fish, and the Japanese red-bellied newt were designed to evaluate development of gravity receptors in microgravity. In the newt, the gravity receptor organ contains sensory hair cells covered by a layer of dense stones or otoconia. The inner ear of juvenile developing newts flown on **IML-2**, showed significantly larger saccular

otoliths and some differences in assembly of components of the otoconia. This implies that gravity influences normal development of gravity receptors. An experiment flown on Spacelab D-1 by Neubert et. al. to test whether the arrangement of statolith organs are affected by weightlessness revealed no effects on flown larvae. An unknown otolith-like structure was found, however; whether this developed because of weightlessness *per se* is not clear. *Xenopus* larvae, returned alive, swam in closed circles at first but returned to normal swimming patterns after one to two days.

Three experiments were flown on D-2 to further evaluate the effect of weightlessness on development of gravity sensing organs. Rahmann et al. compared swimming behavior in larval toad (*Xenopus laevis*) and cichlid fish (*Oreochromis mossambicus*) and demonstrated the strong influence of altered gravity on behavior. Alterations in gravity environment induced somewhat pronounced long-lasting behavioral reactions followed by long-term adaptation to the gravity changes. Changes in brain biochemistry were found in fish and tadpoles subjected to hypergravity (3g) and electron microscopy data showed that after exposure to microgravity energy metabolism was reduced in neurons in the gravity integration center of the brainstem. There were also changes in the gravity-sensitive epithelial cells in the inner ear of fish larvae. The experiment of Horn et al. on D-2 further described specific effects of gravity deprivation on vestibular-ocular reflexes. Eye movements are influenced by two components of the gravity sensing system. One is the otolith organ which is sensitive to linear accelerations and especially to gravity and the second is the semicircular canal organ which is stimulated by angular accelerations. These components interrelate behavioral response and eye movements. The fish youngsters and *Xenopus* tadpoles exposed to microgravity showed some differences in eye movement response. In *Xenopus*, there was a significant effect of weightlessness on the static vestibular-ocular reflex but this was not shown in the fish youngsters. Conclusions are that gravity deprivation acts on developmental process of the vestibular system, if its onset is before the first appearance of the gravity induced response. Animals with reflex experience develop normal vestibular reflex behavior even in the absence of gravitational stimulus. Gravity-associated behavioral changes on D-2 were describe by Neubert et al. Just hatched tadpoles in the ground controls fixed themselves to the chamber walls in the direction of the gravity vector with heads up. In microgravity they fixed themselves to the walls of the culture chamber with heads to the left and tails to the right at a 90 degree angle compared to the ground controls. In agreement with other experiments, swimming behavior was changed. The tadpoles swam in narrow somersaults, in circles or floated motionless in random positions. Some of the fishes swam in large circles or darted around randomly or floated motionless. After return to earth, fishes re-adapted and swam normally after about 16 hours but the tadpoles continued to swim in circles, loops or in screw-like patterns for at least six days. The body morphology of flown tadpoles was sickle-shaped instead of straight probably reflecting the preferred loop swimming mode.

**Avian development** was evaluated on chicken eggs fertilized before launch on SL-J and quail eggs on a series of **Spacelab Mir Missions**. For chick embryos, all tissues including cartilage and bone formed in 7 and 10 day old chick embryos during spaceflight. After flight, these chicks continued to develop and hatched normally.



For the quail experiments flown on the Spacelab Mir Missions, a general description is presented on the Shuttle Mir website, which is in the process of being modified. The following information is from the Shuttle Mir Website and was prepared by Dr. Timothy Jones, NASA Ames Research Center. (See Website address in Appendix E).

“Experiments studying the effects of space flight on embryo development in Japanese quail (conducted in 1990 and 1992 on Mir) revealed that embryonic development and hatching is possible under space flight conditions. However, abnormalities were detected during various phases of this development. The presence of the abnormalities, and the decreased number of hatches in comparison to a control group on Earth, provide some information of space flight effects on embryo development. The exact nature of these effects is still unclear, and it is uncertain whether they may be direct or indirect. The purpose of this investigation, then, is to determine the nature of these effects and the mechanisms by which they occur. Of special interest is the role that gravity plays in the development of the dorsal and ventral sides of the body.

The (Shuttle Mir) experiment began when a set of quail eggs that had been fertilized before launch were sent to Mir on the Space Shuttle. These eggs were incubated (kept at a constant warm temperature) in space on the Mir in a specially designed incubator, and development of the quail embryos was allowed to proceed. Then, during various stages of growth and development, incubation was stopped, and a portion of the eggs were put in a fixative solution so that they could be returned to Earth for later analysis. On Earth, researchers performed postflight analyses on the fixed embryos to determine how microgravity affected the development of the quail eggs, specifically the effects on position and location of embryo organs, formation of a body axis, formation of a visual system (eyes), and development of musculoskeletal systems (deposition of bone and mobilization of minerals, and development of muscles).” ( Readers are referred to the list of principle investigators in Table 8 as a source to search for more detailed results as they become available).

**The response of skeletal tissue cells to microgravity** was evaluated on IML-1 using fetal mouse long bones (metatarsal) from 16-day-old (non-mineralized) and 17-day-old (mineralized) fetal mice. Significant results showed no effect of microgravity on growth or lengthening of long bones during the four-day culture period but a significant reduction in the extension of the mineralized zone in the 16 day-old bones. Decreased mineralization in microgravity was shown also by a 37% reduction in calcium uptake in space compared to the in-flight 1g control and ground control. There was no significant difference between the 1g in-flight control and ground control indicating that mineralization was being impaired in microgravity. Resorption of mineralized matrix was determined by measuring release of calcium 45 from pre-labeled 17-day-old bones. In microgravity, calcium release increased by 37% thus osteoclast resorption in bone is stimulated in microgravity.

# GRAVITATIONAL BIOLOGY AND ECOLOGY

## Significant Scientific Results Summary

### 3. PLANT BIOLOGY

Plant biology experiments were flown on 11 of the 17 Life Sciences Spacelab missions. More than 30 individual experiments, most with multiple objectives evaluating multiple plant types, were conducted addressing the general areas of plant growth and development, gravity sensing and response, metabolism, lignification and support hardware development. Because of the amount of information produced by the Spacelab plant biology experiments, the most significant scientific findings are shown in the Plant Biology Discipline Category tables following this summary. More detailed descriptions of the experiments are included in the Experiment Descriptions section of the Appendix A.

A summary of the results on plant growth and development from experiments performed on a number of plant types (oat, mung bean, anis callus cultures, rapeseed protoplasts, wild carrot, arabidopsis and its mutants and hemerocallis or daylily and a fungal sp.) showed that responses are generally plant type and species specific. Root orientation is strongly dependent on gravity but amyloplasts resting on the endoplasmic reticulum or cytoskeletal elements does not account totally for all gravity-sensing mechanisms in plants and mechanisms are still unclear. Evaluation of columella cells of growing roots fixed in microgravity showed that the amyloplasts are randomly distributed and not located at the side of the cell toward the g-vector as on Earth. In general, seed germination and plant growth progressed well in microgravity. Root and shoot development was evaluated and gravity direction sensing and magnitude of the g-force, or threshold, was determined for a number of plant types. The thresholds, minimum g-force required to elicit a response, were surprising low. Without the access to microgravity, it would have been impossible to determine the threshold value since g-acceleration can be added back in microgravity but gravity cannot be removed (except for seconds in the KC-135 or drop towers and up to 12 minutes in sounding rockets) here on Earth. Use of the NIZEMI centrifuge-microscope allowed visualization of the bending responses of seedling roots. This provided extremely significant information on the influence of gravity related to developing plants on Earth as well as the effects of microgravity. Lignification was significantly reduced in microgravity. Without the requirement to grow strong stems to hold plants upright as in 1g, the plants adapted to microgravity by reducing lignin synthesis.

A potentially commercial processes showing advantage in the microgravity environment was electrofusion. Two types of protoplasts from tobacco leaf tissue were successfully electrofused at a higher efficiency in microgravity because the protoplasts remained in suspension rather than sedimenting thus permitting more contact of the cells and higher fusion efficiency. Leguminous plants formed nodules in presence of Rhizobium bacteria. This showed that gravity is not necessary for normal co-development of nitrogen-fixing bacteria and leguminous plants and is important information for future cultivation of legumes on space stations, long-duration missions or Lunar outposts. A commercially developed and available plant growth facility, Astroculture™,

allowed cultivation of potatoes (1.5 cm diameter in approximately 16 days) in microgravity. Technology developed as a part of this facility is being used for ground-based purposes ranging from treatment of cancer patients to horticulture. Still in the area of plant growth facilities development, the Greenhouse experiment conducted in the Russian/Slovakian-developed plant growth facility called the "Svet" was launched on SL-Mir. Probably one of the most complex plant experiments ever attempted in space, the facility grew plants for 90 days on Mir to allow seed-to-seed growth. (A description is given at the end of this section).

The following table presents a summary of results from the Spacelab plant biology experiments.

## DISCIPLINE CATEGORY- PLANT BIOLOGY

### Experiment Specific Category - Growth and Development

Mission	PI	Species	Results and Comments
OSS-1	Slocum	Oat	Seedlings normal, normal ultrastructure features Cortex cell mitochondria morphology appeared swollen More vacuoles in peripheral root cap cells
		Mung bean	Normal tissue organization Root cap cells in flight samples collapsed and degraded Ultrastructure showed 1) loss of organelle integrity 2) highly condensed cytoplasm

This experiments germinated seeds just hours before launch

Conclusions: Loss of putative gravity-sensing cells may be very significant for long-term plant orientation in space. Demonstrated differing tissue sensitivity in the two species grown in space.

OSS-1	Krikorian	Oats	Root lengths 6% less than controls Number of roots growing upward 74% compared to 0% for ground Much chromosome fragmentation and breakage Root tips seemed more adversely affected than shoot growing regions Metaphase chromosomes generally more contracted and poorer spread
		Mung Bean	Number of cell divisions about half normal ground grown seedlings No grass morphological changes Metaphase chromosomes generally more contracted and poorer spread

This experiment germinated seeds just hours before launch

D-1	Theimer	Anis callus cults	90% of cell clones showed polarity - primordia of leaves and/or roots Electron microscopy of roots showed well developed statocytes with amyloplasts Growth into normal anise plants after landing
IML-1	Rasmussen	Rapeseed Protoplasts and embryonic cell line of carrot (Dacus carota)	Protoplasts in microgravity delayed synthesis of new cell wall Single cells were enlarged, formed few aggregates vs ground controls were small, 8-12 aggregate Calli from protoplasts exposed to microgravity had highly reduced growth  Growth into normal plants after landing (12 and 16 weeks after landing) 3-day old protoplasts mainly contained large cells with big vacuoles and 2-4 cells per aggregate compared to ground with smaller cells and 8-19 cells/aggregate Most significant results: retarded regeneration process possibly due to initial effect on cytoskeleton or stress of spaceflight On the ground, cells concentrate in a layer perpendicular to gravity vector, while in microgravity protoplasts were randomly distributed causing absence of cell-cell interaction
IML-1	Briarty	Arabidopsis thaliana and its aux-1 mutant	Objectives were to determine root and shoot growth rates, to observe hypocotyl hook Root, shoot and total length in space-grown plants not different from ground In microgravity there was no obvious orientation of root and shoot Angle of hypocotyl hook was different in microgravity compared to ground No differences seen in cotyledons Significant difference in cytoplasmic volume, more occupied by lipids in space samples
IML-2	Krikorian	Hemerocallis (Daylily)	Successful somatic embryogenesis but more slowly in space Increased occurrence of binucleate cells Chromosomal aberrations and reduced cell division rate not due to re-entry effects (cells fixed in microgravity)
SL-J	Miyoshi,	Neurospora crassa	To understand development of circadian rhythm in microgravity in the mold, <i>Neurospora</i> . Results: Both flight and ground showed five definite conidium band patterns of circadian rhythm.

Growth of *Neurospora crassa* was increased in microgravity compared to ground

**Experiment Specific Category: Gravity Sensing**

Mission	PI	Species	Results and Comments
D-1	Perbal	Lentil	<p>No significant difference in length of lentil roots</p> <p>Roots showed variable orientation in microgravity, 1g roots grew toward the g-vector</p> <p>Roots grown in microgravity and placed on the 1g in-flight centrifuge showed strong gravitropic curvature proving that the statocysts which had never sensed gravity were capable of responding to centrifugal acceleration.</p> <p>The amyloplasts in statocytes grown in microgravity gathered in the center of the cell while those developed in the 1 g centrifuge showed normal polarity with the nucleus near the proximal wall, endoplasmic reticulum near the distal wall distance from the endoplasmic reticulum.</p>

The significant findings from this experiment was that it demonstrated that the statolith could not exert pressure on the endoplasmic reticulum because of distance in location of the two organelles in the cells in microgravity. Thus, statolith contact or pressure on the ER is not the mechanism for gravisensing. This association of statoliths and the ER in gravisensing could not have been clearly separated under normal ground conditions.

D-1	Volkmann	Cress roots ( <i>Lepidium sativum</i> )	<p>Germination rate in microgravity is the same as 1g.</p> <p>Growth curves are similar for all three conditions, similar growth kinetics</p> <p>In ground controls, roots grew mostly parallel to the gravity vector while in space, roots grew at angles up to 60 deg with reference to the seed plate</p> <p>Statolith structure was the same as ground samples thus structural polarity was maintained thus, structural polarity is genetically determined</p> <p>Statocysts had less parallel ER</p> <p>Amyloplasts were more rounded and starch grains had clear areas in their centers and the amount of starch was lower than 1g cells</p>
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Seeds were germinated in space.

The most significant result: structural polarity that persists in space-grown plants is genetically determined.

IML-1	Perbal	Lentil roots (Lens culinaris)	The objective of the experiment was to measure bending response times to determine effect of microgravity and threshold of gravity force needed to elicit the response. Results: Roots bend in response to changes in orientation of gravitational field. The bending was quantitatively estimated by measuring the minimum duration and the total duration of the stimulation required to produce a bend response.
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Seeds were germinated in space.

Data and calculations showed consistency with the hypothesis that amyloplasts exert pressure on the cytogel lining of the longitudinal wall of statocytes. Alternatively, the amyloplasts may exert tension on the actin filament network as a gravity detecting mechanism.

IML-1	Heathcote	Wheat (Triticum aestivum)	Objectives: to evaluate seedling curvature exposed to phototropic stimulation. Results: Curvature response in microgravity was not significantly different from ground Relationship between stimulus and curvature response was shown The dose (light exposure duration) curve was not significantly different in space vs. ground and seedling curvature did reverse curvature (autotropism) in microgravity Circumnutation (oscillations) was seen in 50% of flight seedlings
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Three-day old coleoptiles were used.

IML-1	Brown	Oat (Avena sativa)	Objective: to determine threshold time and g-force intensity for gravity response in seedlings Results: Curvature response in microgravity not greatly different from ground The shortest gravity stimulation to cause a response in 1g was 2.0 min., the threshold extrapolated at less than 1 min. In flight the least g-value applied was 0.1 g and this caused a significant bending response thus if there is an absolute threshold for gravitropic response, it must be below 0.1g.
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Seeds germinated in space in the dark and gravity was added back incrementally by use of a variable speed centrifuge

D-2	Hock	Bassidio- myces (Flam- mulina velu- tipes)	Fruiting bodies exhibited random orientation in microgravity. Ground fruiting bodies point exactly opposite direction of acceleration force. Results: Fruiting bodies in microgravity grew away from the substrate No impairment of cap morphogenesis and growth intensity.
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Flat stipes indicated that acceleration force is required for regular development of stipes. Ultrastructure of the graviperceptive growth region of the stipe did not show sedimentable cell components that could act as statoliths.

Significant conclusions: This experiment revealed two totally different growth reactions: the gravity independent avoidance reaction shown by growth opposite the substrate and the gravity-dependent orientation shown by random orientation in space-flown samples compared to orientation opposite the direction of the gravity vector in controls. In addition, this experiment showed that gravity is required for proper development of the stipes in fungi and also, this experiment showed that fungi do not have statoliths for sensing gravity. Gravitropic bending involves growth inhibition at the upper side of a horizontally oriented transition zone. Accumulation of vesicles at the lower part of this region was the first ultrastructurally observable response to altered acceleration. These vesicles cause expansion of the central vacuole and subsequent differential enlargement of the lower side of the stipe leading to directional bending based on gravitational force direction.

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D-2	Volkman	Cress	Objective: investigate graviperception on plants by determining the threshold values for minimum gravitational force inducing a bending effect in roots. Results: In microgravity roots exhibit larger bending angles and root curvature begins early after adding g-force stimulus compared to ground. Gravity-grown roots can sum two stimuli of intensity Amyloplasts in microgravity roots were distributed at random.
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Seeds were germinated in space.

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IML-2	Volkman	Cress	Objective: to determine whether for gravity controlled processes the reciprocity law is operable. (i.e. equal gravity doses (gravity x time) would give equal results without regard of individual values chosen for acceleration (above threshold). Results: In general, roots grown in microgravity respond to g-stimulus in shorter times after stimulation than roots grown in the 1g centrifuge and the degree of curvature was larger for microgravity roots. Results showed that the gravitropic curvatures produced by gravity doses were not the same and do not confirm the reciprocity law.
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Seedlings were germinated in microgravity and curvature of roots was observed with the NIZEMI variable rate centrifuge and microscope.

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IML-2	Perbal	Lentil	<p>Objective: to determine whether settling of statoliths onto the endoplasmic reticulum regulates growth response in root growth. Root orientation is strongly dependent on gravity.</p> <p>Results: In microgravity there were strong oscillations of the root tip Curving to right and left were similar indicating that there was no memory of the direction imposed by 1g. Root length, growth rate and cell elongation length in microgravity were not significantly different from 1g. The transfer from 1g to microgravity did not modify cell elongation in the roots. The root cap has at least one inhibitor that regulates root growth. The results of this experiment showed that symmetrical release of this inhibitor is not gravity dependent.</p>
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Seeds were germinated in microgravity.

A significant finding is that in statocytes, the sedimentation of amyloplasts onto the endoplasmic reticulum should not induce any signal of cell elongation. Yet, there is a definite effect of gravity on root orientation and growth and the mechanism has yet to be found.

IML-2	Sievers	Chara Thalli	<p>Objective: to test a safe fixing device and procedure to investigate ultrastructure of organelles and cytoskeletal elements.</p> <p>Results: The device and procedure were validated In Chara, vacuoles containing barium sulfate particles are located about 10-30 microns from the outermost apical cell wall and function as statoliths. Statoliths do not fall on the apical cell wall in 1g because they are suspended by an actin network. In microgravity, statoliths translocated towards the base of the cells</p>
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Rhizoids grew 18 hours in darkness at 1g before launch and 30 hours in microgravity.

IML-2	Iversen	Brassica napus L Wild type and agravi- tropic transgenic B. napus L	<p>Objective: to evaluate growth, morphology, and gravitropic sensitivity.</p> <p>Results: Both wild-type and the agravitropic Brassicas showed expected root elongation. Ground studies showed significant difference in root growth rate between wild type and in microgravity no difference between root growth rate occurred in wild type. Subjectively, total growth in both types was higher for ground control than space grown transgenic roots. On the ground, the wild type showed normal curvature, agravitropic roots showed no response to gravity vector direction. In microgravity, both root types were agravitropic</p>
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After flight, unfixed samples were cultured for 24 months. Flown plants still showed agravitrophic behavior. Ground controls were capable of regeneration into intact plants however, no plants could be regenerated from flown samples

The most significant conclusion was that difference in growth in the ground control between wild-type and the agravitrophic root type appeared to be eliminated in microgravity.

Pre-flight, preps were kept cold to retard growth before launch and until start of the experiment in microgravity.

IML-2	Johnsson	Cress roots	Objectives: to test whether characterizations for "Random Walk" are valid for growth of cress roots in microgravity. Random walk is characterized by mean value of deviation angles of root tip at a given time being zero and the variance of the mean square value of deviation angles will increase linearly with time. Results: In microgravity the observed growth patterns and linearity of deviation patterns with time followed the predictions of random walk hypothesis. Also observed that, length of cress roots in microgravity was shorter than ground Curvature of root at a particular point changed with time in microgravity but not in the 1g centrifuge
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Initiation of the experiment in microgravity began by transfer of containers from 5 deg. C to 23 deg C.

IML-2	Haeder	Euglena gracilis	Objective: to investigate whether Euglena has an active gravireceptor and to determine the threshold for graviperception. Euglena are unicellular photosynthetic freshwater flagellates that normally exhibit negative gravitaxis. Results: Threshold response to acceleration was between 0.08 and 0.16 g indicating a very low g- level orientation response for Euglena. The dose-response curve (more g-force applied) was sigmoidal indicating of active physiological gravireceptor rather than passive mechanical reorientation due to asymmetry of the baricenter of the cell. Swimming behavior under applied accelerations showed that the cells swim at a speed that is a vectorial addition of their propulsion velocity and the sedimentation velocity. In microgravity cells swim at about 160 microns per second and the value for 1g is 130 microns per second,
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when the swimming is against acceleration. This corresponds well to sedimentation rate of 30 microns per second for immotile cells at 1g.

USML-2	Hilaire	Starchless Arabidopsis mutant	Objective: to compare location of starchless plastids in columella cells mutant Aarabidopsis seedlings in microgravity, centrifuged, and clinorotated. Results: In stationary seedlings starchless plastids were equally located in the mid- and distal third of the columella cells. After centrifugation of these seedlings at 20g for 5 minutes, starchless plastids were sedimented to the distal third of the cells. Plastids from flight were distributed in the proximal third. Clino-rotated seedlings had plastids mostly in the middle third of the columella cells.
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Significant conclusions were that the density of the plastids without starch does not prevent redistribution based on gravity treatment. Also, on a cellular level, clinorotation is a poor simulation of microgravity with this organism and under the conditions of the test.

### Experiment Specific Category: Plant Metabolism

Mission	PI	Species	Results and Comments
D-1	Jung-Heiliger	Horse Chestnut (Aesculus hippocastanum L)	Objectives: to study calcium uptake inhibitor on production of secondary metabolites of a pharmaceutically relevant cell culture. Results: No changes in secondary metabolism were detected in microgravity samples. Nifedipine (calcium uptake inhibitor) reduced the formation of hydroxybenzoic and hydroxycinnamic acid derivatives. Additional findings: viability was 70% in microgravity compared to 80% for ground at comparable sampling times. Nifedipine reduced viability to about 25 % for both flight and ground samples. No differences in ultrastructure were seen between flight and ground samples. Cosmic radiation and other conditions of spaceflight did not affect ploidy level. <u>Plantlets from suspension cell cultures plated on solid nutrient medium could be grown.</u>
D-2	Hampp	Protoplasts of leaf tissue	Objectives: to achieve electrofusion of the two protoplasts types in microgravity and to investigate metabolic response in the protoplasts generated.

of Nicotiana tabacum and Nicotiana rustica	Results: Electrofusion was successful (20% were identified as hybrids) and the protoplasts generated showed good viability in flight and ground, Development was in the normal range for all cultures Protein content was stable, specific cytoskeletal polypeptides (actin and tubulin) were not influenced by microgravity. Metabolites including ATP, ADP, NADH, NADPH, NAD AND NADP showed kinetics typical for regenerating protoplasts and 1g in flight and ground controls virtually identical. In microgravity, relative increase in ATP, NAD(H), and NADP(H) were reduced. Ratio of reduced and oxidized pyridine nucleotides (NADH/NAD) and ATP/ADP was lower. Fructose-2,6-biphosphate content in microgravity was decreased. This suggests relative increase of gluconeogenesis over glycolytic activity
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Significant conclusions: The combination of growth and metabolite parameters toward down-regulation of energy metabolism in microgravity yet growth and cell division were still about the same as for 1g.

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D-2    vonKeller	Sunflower (Helianthus) Mesophyll and Hypocotly Protoplasts	Objective: to achieve electro-fusion of the two species of sunflower protoplasts. Results: The fusion rate in microgravity was 25.5% whereas ground fusion was 25.2% in one set and 26% in microgravity compared to 15% for ground in a second set of electro-fusions. The final yield of hybrids in microgravity was 13 % compared to 1g at less than 4.5%
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Significant conclusions: Electro-fusion in microgravity is more efficient because on the ground the cells sediment before forming heterospecific fusion partners.

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USML-2	Gallegos	Arabidopsis thaliana wild type and 3 starch altered mutants	Objectives: To evaluate ethylene production in three starch altered mutants and wild type Arabidopsis thaliana in microgravity, and ground static and rotated plants. Results: Ethylene production was very high in all three mutants for all gravity conditions. The wild-type produced significantly more ethylene in static plants. Horizontal clinorotation resulted in higher ethylene production than static and vertical rotation in the wild type plants <u>Static and vertical rotation plants produced the same amount of ethylene</u>
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USML-2	Wong	Clover plants and Rhizobium	Objective: to investigate whether nodulation process can occur in microgravity and whether gravity is important in the recognition of legume by Rhizobium. Results: All plants developed 2 to 3 nodules. All nodules were induced by Rhizobium strain TA1 suggesting that the early steps for nodulation in legumes can occur in microgravity.
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### Experiment Specific Category -Lignification

Mission	PI	Species	Results microgravity versus ground
OSS-1	Cowles	Mung bean Pine seedlings Oat seedlings	Objectives: to evaluate root/shoot orientation and lignification in seedlings germinated in space. Results: Flight seedlings were shorter than controls in all three species. 25 to 40% of the bean and oat roots grew upward and mung bean roots were disoriented. Flight mung beans had a significant reduction in lignin content compared to controls. In flown pine seedlings, phenylalanine ammonia-lyase and peroxidase activities were reduced.

The most significant finding was that the lignin synthesis is reduced in microgravity.

OSS-1	Cowles	Mung bean Pine seedlings Oat seedlings	Objectives: to evaluate lignification in microgravity Results: Overall reduction of lignin in pine seedlings was 4 to 5 % while the flight mungbeans produced significantly less lignin than ground controls. Seedlings grew towards the light and almost half of the roots grew toward light as well and 25-40% of mung bean and oat roots grew towards the light. Flight seedlings were shorter than ground.
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Results supported the hypothesis that lignin synthesis is reduced in microgravity.

SL-2	Cowles	Mung bean Pine seedlings Oat seedlings	<p>Objectives: to evaluate root/shoot orientation and lignification in seedlings germinated in space.</p> <p>Results: Lignin content of flight seedlings was significantly reduced in all three plant types compared to the 1g controls. In young pine seedlings, lignin content in flight seedlings was 13% less than ground controls.</p> <p>Mung bean and oat seedlings averaged 23 to 24% less lignin than controls.</p>
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These data confirm the results of the earlier experiment on OSS-1 that gravity is an important factor in lignification.

LMS	Lewis	Loblolly pine Douglas fir	Objectives: Information will be available in 1999
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## SUMMARY OVERVIEW

### Plant Growth Support Hardware

The Astroculture™ plant growth facility, developed by the Wisconsin Center for Space Automation and Robotics (WCSAR), a NASA Commercial Space Center, was flown on Spacelab USML-1, the Spacehab -1 and -2 missions and Spacelab USML-2. The following is a modification of a description provided by Dr. Ray Bula, Director of WCSAR. (See website addresses, Appendix E).

As our stays in space become longer, it will be necessary to grow plants to minimize the cost of life support. Plants can help provide food, oxygen, and pure water and can also assist in removing carbon dioxide from human space habitats. However, since fluids behave differently in microgravity, plant watering systems that operate well on Earth do not function effectively in space. A useful plant growth system must be able to deliver nutrients to the plants without releasing solutions into crew quarters. Such a system must also be capable of controlling levels of moisture or humidity in the air. Excessive levels of humidity can damage experiments and equipment, while insufficient humidity can have a detrimental effect on plants. The moisture in the air also represents an valuable on-orbit commodity that could be recycled as condensed water for cooking, drinking, or as a source of water for plants. Additionally, electrical power is a valuable resource on orbiting spacecraft. This requires that plant growth systems must be able to provide light as efficiently as possible.

The Astroculture™ system contains three subsystems that address these issues and provide superior environmental control for plant growth in an inexpensive and reliable spaceflight package. First, the water and nutrient delivery system uses porous tubes with different pressures to ensure a proper flow through the rooting matrix. This system has proven itself to be effective during long-duration flights in the microgravity environment. Second, the efficient subsystem for controlling moisture in the growth chamber humidifies and dehumidifies the air without needing a gas/liquid separator, which is required by all other systems currently in use, to recover the condensed water. Third, the lighting subsystem uses light-emitting diodes (LEDs) to provide high levels of light within the limits of electrical power available on orbit and with greater safety than any other light sources currently used by space-based plant growing facilities. The experiment package is sealed, with cooling provided by an experiment heat exchanger and carbon dioxide (necessary for photosynthesis) supplied from a storage tank.

This equipment was used to grow potato plants on USML-2 as part of a cooperative experiment with the Secondary Payload Programs of NASA's Life and biomedical Sciences and Applications Division to obtain data on the nature of starch accumulation in microgravity. Starch is an important energy storage compound in plants, and there are some indications that starch accumulation in plants is restricted in microgravity. To investigate this phenomenon, small potatoes were grown in the Astroculture™ facility. They were developed from potato leaf cuttings with auxiliary buds, which can be induced to develop small tubers filled with starch in 10 to 15 days. The experiment evaluated rates of photosynthesis, movement of photosynthesis products from leaves to tubers, conversion of sugars to starch in the storage organs, and enzyme

activities for the formation and degradation of starch. Investigators also studied the number, size, shape, and distribution of starch grains and the structures that form starch (amyloplasts).

The USML-2 flight of the Astroculture™ hardware is the last of a series of tests to evaluate each of the critical subsystems needed for the construction of a reliable plant growth unit. On the previous missions, lighting, humidity, pH, nutrient supply and composition, and carbon dioxide and atmospheric contamination subsystems were validated. After flight-qualification on USML-2, a functional plant growth unit can be available for sale or lease to commercial enterprises. The technologies used in the Astroculture™ flight unit have resulted in several commercial products for use on Earth. The lighting subsystem has been the basis of the development of a unique lighting system for photosynthesis research. The lighting technology is also being used in some novel medical applications, ranging from measuring blood sugar levels to use in photodynamic therapy for cancer patients. Other applications of the Astroculture™ technology include improved dehumidification/humidification units, water-efficient irrigation systems and energy efficient lighting systems for large scale commercial nurseries.

#### **Description of the Astroculture™ experiment flown on USML-2**

The objectives of the experiment were to evaluate the performance in microgravity of the Astroculture™ system and to study how starch accumulation in plants is affected. Leaf cuttings were taken from potato plants and placed in the Astroculture™ hardware approximately 36 hours before launch. On orbit the crew monitored the automated operation and status of the plant material via a video camera. Results showed that the Astroculture™ hardware, a totally enclosed chamber, provided the environment required to support plant growth in microgravity during the 16-day mission. This was the first time plant material had been grown in microgravity in such a totally enclosed controlled environment chamber. This is significant since any plant growth response could be attributed to microgravity rather than lack of environmental control of critical factors such as temperature, lighting and humidity. Downlink ability allowed real-time monitoring of development of the tubers. The Astroculture™ hardware provided remote site capability for monitoring mission activities to involve the scientists in the ongoing mission activities and increasing the science information learned for application to future missions.

Results showed that the potato leaf cuttings maintained their vigor and turgidity during the first 12 days in microgravity before naturally beginning to senesce during the last 4 days of the mission. The cuttings maintained active rates of photosynthesis and respiration. The leaf cuttings produced tubers (potatoes) that averaged 1.40 grams, fresh weight, and had an average diameter of 2.5 cm. The ground controls produced tubers that averaged 1.51 grams, fresh weight and an average diameter of 1.5 cm, the same as flown tubers.

The significant conclusions are that the success of this experiment clearly demonstrated the successful operation of the Astroculture™ hardware. In addition, the experiment also demonstrated that potato plants can be induced to produce tubers in the microgravity environment.



**The "Svet" Facility Launched on SL-Mir: Greenhouse - Integrated Plant Experiments on Mir.** Plants can be grown in microgravity and utilized effectively in life support systems. The goal of the Greenhouse experiments is to study plant growth in microgravity and to determine the effects of spaceflight on the ontogenesis, reproductive function, metabolism, and productivity in plants, specifically dwarf wheat.

The Greenhouse experiment is conducted in the Russian/Slovakian-developed plant growth facility called the "Svet". This is probably one of the most complex plant experiments ever attempted in space. It has involved over thirty investigators and has required complex engineering development as well as ground-based, preflight and postflight experimentation. According to original plans, this experiment was to grow Super-Dwarf wheat in space for 20 days during Mir 19. This was subsequently extended to 90 days by allowing the experiment to continue during Mir 20; this made it possible for investigators to attempt a seed-to-seed experiment. Plant development is monitored by daily observations and photographs taken by crewmembers, and plant samples are collected at specific developmental stages and at final harvesting. All samples are returned to Earth for postflight analysis. The wheat planting which began on the Mir 22 mission will continue to be monitored on the NASA 3 long duration mission. In addition, a third planting will also take place during this mission.

The Svet is a greenhouse designed jointly by the Institute for Biomedical Problems (IBMP) and the Space Research Institute of the Bulgarian Academy of Sciences for the study of plant growth in space. It is located in the Krystal module of the Mir Space Station and was first used on Mir in 1990 in an experiment using cabbage and radish seedlings. The Svet consists of four basic units: the plant growth chamber, root module (also called vegetation module), light unit and control unit, and GEMS. Recent modifications to the Svet include improved lighting and watering systems to enhance plant growth conditions and the addition of an instrumentation system to gather information on how microgravity affects the gas exchange process in plants.

On the SL-Mir STS-71 mission the experiment objectives of principal investigators F. Salisbury and M. Levinskikh were to investigate the effects of microgravity on the productivity of a crop plant, specifically dwarf wheat, to identify the chemical, biochemical, and structural changes in plant tissues induced by microgravity, to determine microgravity's effect on plant processes, such as photosynthesis and water use and to evaluate current facilities for plant growth aboard the Mir. These tests on Mir are continuing to provide significant information. SL-Mir on STS-71 delivered the root module and seeds to the Mir Space Station for the experiment to be started during the Mir 19 mission. Facility modifications were performed during Mir 18, including the addition of US provided water sensors for the root module, infrared sensors for leaf temperature, illumination sensors to measure light levels and application of reflective mylar film to the Svet chamber walls to enhance light levels.

Mir 19: Two seed plantings of wheat occurred during Mir 19, which began after the Space Shuttle STS-71 mission undocked from the Mir station. Plant development was monitored by daily observations and photographs taken by the Mir 19 crew.

Mir 20: Although the plants grew for almost the entire 90 days of the experiment, failure of four of the six fluorescent lamp sets resulted in low lighting. The low lighting levels, added to the fact that the moisture content in the root module was not kept at optimal levels, resulted in poor growth of the plants. One of the most interesting observations of the experiment was that the plants remained vegetative, that is, they were constantly in a state of reproduction throughout the experiment. The investigators have hypothesized that the microgravity environment contributed to the vegetative condition of the plants.

STS-74: Plant samples and equipment (root module, lamp bank, controller and hard disks) were transferred to and brought back to Kennedy Space Center by STS-74, where they were divided among U.S. and Russian investigators for further analysis.

STS-76 delivered a new root module, fixative kit and logbook to the Mir space station. A Russian Progress ship delivered a new light block and some spare parts soon after the launch of STS 76.

Mir21/NASA2: A new set of wheat seeds was planted about midway through this mission. Plant development was monitored by daily observations, photographs and video taken by the Mir 21 and NASA 2 crew.

STS-79 carried a dry stowage kit and new leaf bags up to the Mir Station. The new leaf bags were installed in the Svet.

Mir22/NASA3: Experiment operations continued as plant growth and activity were monitored by daily observations, photographs, and video recordings. The final harvest of the plants that were planted during Mir 21 (known as the seed-to-seed experiment) occurred on January 17, during the docked phase of the STS-81 mission. The second crop planting, which was originally scheduled to occur during the Mir22/NASA3 increment, was not performed. .

STS-81: Fixed samples from the seed-to-seed experiment were returned to Earth for analysis on the STS-81 flight. The Svet/Greenhouse hardware was dismantled and stowed on the Mir until its next usage during the NASA 5 increment.

This information was taken from the Shuttle-Mir Web (See Appendix E for address)  
Last Update: 22 December 1997

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## **GRAVITATIONAL BIOLOGY AND ECOLOGY**

### **Significant Scientific Results Summary**

#### **4. RADIATION BIOLOGY**

Experiments to evaluate radiation levels and effects on living systems and to obtain information on levels of radiation within the spacecraft and Spacelab were flown on five of the 17 Spacelab

missions that included Life Sciences payloads. Sixteen radiation experiments were flown, ten of which evaluated effects on life forms including insects, bacteria, mammalian cells, nematodes, yeast, and plants. Five experiments provided information on the levels of radiation in different locations on the Shuttle and in some of the experiment specific hardware including Biorack, the access tunnel, pallet, and the Shuttle middeck. One experiment reported dosimetric information on crew. Radiation has been an topic of biomedical concern since the beginning of human spaceflight and must betaken into consideration, either as to effect on individual experiments or experiment specific hardware shielding) when any biological experiments are conducted in space.

The primary type of radiation evaluated, HZE, is cosmic radiation produced by heavy, high energy and charge particles (ions) from neutrons released by interactions of primary galactic radiation with the Earth's atmosphere. This densely ionizing component of cosmic radiation is most damaging to cells and tissues. Hits by HZE cause damage to cells from the nuclear disintegration stars produced by protons and neutrons in the irradiated tissue. Another type of radiation that should be considered comes from ionizing components of the radiation field. These include photons, electrons, muons, pions and protons. The following tables give mission information related to radiation experiments. More detailed information may be found in the Experiment Descriptions included in the Appendix A.

### RADIATION LEVELS ON THE SHUTTLE, SPACELAB AND EXPERIMENT-SPECIFIC HARDWARE

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Location Evaluated	Radiation Type	Principal Investigator
SL-1	STS-9	1983	10+	Spacelab Access tunnel Pallet	Overall dose and HZE	Shopper, E.
Spacelab D-1	61-A	1985	7+	Biorack	HZE and Ionizing	Buecker, H.
IML-1	STS-42	1992	8+	Biorack	HZE	Reitz, G.
IML-2	STS-55	1994	14+	Biorack Shuttle middeck Spacelab	Ionizing and HZE	Reitz, G.
Spacelab D-2	STS-55	1993	9+	Spacelab Access tunnel Pallet	Overall dose and HZE	Shopper, E.

Information from SL-1 showed that overall dose measurement in milli-rads (mrad) and observed HZE particles vary as a function of spacecraft location and inclination and it is important to consider that the South Atlantic Anomaly is directional (protons are primary contributors) while galactic heavy ion flux is omni-directional. On SL-1, inside the Spacelab module, the overall absorbed dose varied from 102 to 143 mrad and 190 mrad on the pallet. The HZE particles varied from 42 to 167 tracks per square centimeter.

Components of the Biorack facility were evaluated for radiation on IML-1. Eight track-detector stacks placed inside Biorack Type I containers were used for measurements. Two of the stacks were placed in the 37°C incubator, four in the 36° C incubator and two on the 1g centrifuge. Plastic track detectors gave measure of flux of heavy charged particles. Nuclear disintegration stars were determined in nuclear emulsions. Results showed that thermal neutron flux was at least 0.7 neutrons per square centimeter per second. The conclusion from the IML-1 experiment was that the radiation exposure on astronauts during the mission was higher than the mean annual public exposure but well below the limits defined for spaceflight. (Specific values are listed in tables for this experiment in Appendix A). Similar tests were done on IML-2 to evaluate locations inside Biorack, shuttle middeck and Spacelab. IML-2 had an inclination of 28.5 degrees and an altitude of 296 km. (IML-1 had an inclination of 57 degrees and flew at 302 km altitude). Measured radiation was mainly due to protons of the South Atlantic Anomaly of the radiation belt. Thermal neutron flux accounted for some radiation. A dose rate of about 3.4 micro Gy/day in tissue was calculated as an estimate. Heavy ion flux in different positions within Biorack varied between 0.5/cm and 0.2/cm. Comparison of results from IML-1 and IML-2 showed a higher heavy ion flux variation for the different locations in IML-2 (a factor of more than six compared to a factor of two in IM-1). Thus the conclusion was that the only way to obtain confident information about radiation intensity and type is to measure radiation on each mission in the vicinity of the experiment of interest. Assumptions made that the Biorack facility components shield biological experiments may not be totally valid. A similar measurement of the same general areas of Biorack on D-1 provided additional information that experimental conditions for biological experiments in space must consider that dosimetric data may not be sufficient for proper assessment of test data. At the cellular level, hits are not evenly distributed and thus averaging of radiation doses in the general area may not provide accurate information for the experiment. Information from D-2 indicated that highest measurements were obtained in the Spacelab tunnel, the Spacelab end cone, an experiment rack near the end cone.

### **Effects of Radiation on Living Organisms.**

Results from a large variety of test organisms in different developmental stages placed in different locations on the Shuttle have provided a database on radiation effects. On Spacelab-1 a sandwich-like combination of thin foils of different types of tissue-equivalent nuclear track detectors of various sensitivity were used to detect radiation due to HZE particles. The foils were interspersed with layers of biological test organisms to allow analysis of tracks of the HZE particles and relate this to the effect on individual organisms in the foils. Results from SL-1 agreed with previous results from Apollo and the Apollo-Soyuz missions. Even single HZE particles can induce dramatic effects in individual cells. From these experiments, it became evident that modeling radiation damage markedly underestimated the real effects and actual damage to cells and organisms. Dosimetric data from SL-1 and previous biostack experiments are listed in the

Experiment Description section, Appendix A. (Reitz, G. Radiobiology mapping: advanced biostack experiment).

## EFFECTS OF RADIATION ON LIVING ORGANISMS

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Species Studied	Principal Investigator
SL-1	STS-9	1983	10+	Bacillus subtilis Mixed species Arabidopsis thaliana	Horneck, G. Reitz, H. D. Kranz, A. R.
Spacelab D-1	61-A	1985	7+	Crasus morosus	Buecker, H. J.
IML-1	STS-42	1992	8+	Crasus morosus X-rayed yeast Yeast mutants Nematode	Buecker, H. J. Ross, H.D. Nelson, G. A.
SL-J	STS-47	1992	7+	Corn seeds Soy bean seeds Artemia salina eggs B. subtilis and plasmid Drosophila melanogaster	Nagaoka, S. Ikenaga, M.
Spacelab D-2	STS-55	1993	9+	Bacillus subtilis Deinococcus strains E.coli plasmid pBR 322	Horneck, G.
IML-2	STS-65	1994	14+	E. coli strains Skin fibroblasts (primary)	Horneck, G.

On SL-1 and D-2, experiments were conducted to evaluate the effects on prokaryotes of vacuum and solar ultraviolet radiation, separately and in combination. While sunlight provides the energy that is the basis for life on Earth, UV radiation has adverse effects on living organisms. Part of the UV is completely absorbed by the Earth's atmosphere but some of the UV (280-315 nm) reaches the surface. The amount of this damaging UV that reaches Earth's surface depends on many factors, the most important of which is the stratospheric ozone layer. An objective of experiment on SL-1 and D-2 was to study the full spectrum of extraterrestrial UV-radiation and/or space vacuum on a prokaryote. Spores of *Bacillus subtilis* strains were exposed to the full ultraviolet spectrum (>170 nm) including selected ranges of wavelengths of 220, 240, 260, and 280 nm. For vacuum exposure, the organisms were placed either in hermetically sealed or unsealed containers vented to the outside. Containers were placed on the pallet of S- 1. Results from SL-1 showed that vacuum exposure for 10 days reduced viability to about 50 % of samples at 1 atm. In the

ground-based test, vacuum only slightly reduced viability of the spores. Additionally, in space, a 10-fold higher frequency of histidine prototrophic mutations occurred. For spores subjected to radiation and vacuum, there was a nine times higher sensitivity than resulted in spores radiated but maintained at 1 atm . Repair-deficient strains of *B. subtilis* showed higher UV sensitivity than the wild type strain and sensitivities of flown strains were more sensitive than ground.

On **D-2**, 308 biological samples were exposed to UV, vacuum, or a combination of both. As shown on **SL-1**, reduced survival of *B. subtilis* was more evident in samples exposed to both vacuum and UV-radiation. Survival was affected by the repair capacity of the strains investigated and injury of the spore DNA in the form of DNA strand breaks was assumed to be the mechanism of damage. Simulated ground-based data on ozone depletion showed a strong increase in biological effect with decreasing ozone concentration.

Seeds of *Arabidopsis thaliana* were flown on **SI-1** to evaluate the outcome of heavy ion particle radiation (**HZE**) on germination, growth and development. Seed embryos were evaluated in which HZE-tracks were found running through or near the root or shoot meristem. Sixty-three percent of the embryos hit or grazed by one cosmic HZE-particle inside the root meristem showed lethal damage and 18.1% had abnormal root growth. Embryos in which shoot meristem was hit or grazed by a single HZE showed 90% lethality and abnormal growth occurred in 10% of the survivors. This experiment provided very significant confirmation that a lesion caused by only one cosmic heavy ion is capable of affecting initial process of gravitropic response in plant roots.

**Eggs of the stick insect, *Carausius morosus***, have different sensitivities when exposed to cosmic radiation at different developmental stages. Experiments flown on **Spacelab D-1** and **IML-1** show that effects of HZE particles (heavy ions of high charge and energy) from cosmic radiation combined with microgravity are synergistic. The early stages of development were highly sensitive to single hits of cosmic ray particles as well as to microgravity. The rate of anomalies was about 10% for flown samples compared to 1.2% for ground controls. There was a significant decrease in hatching rate for eggs and a very high proportion of malformations in the group of eggs hit by an HZE particle in microgravity. Deformations were found in abdominal segments, antennae and the extremities. A delay in growth was attributed to cosmic radiation from hits by HZE particles. The rate of anomalies was about 10% for all groups of flown samples compared to less than 1.2% for ground controls. Yeast cells irradiated with X rays before launch were capable of repairing some of the damage, however; the repair rate was reduced in microgravity samples.

The **nematode, *Caenorhabditis elegans***, evaluated by **Nelson** on **IML-1** showed normal gross anatomy, symmetry and gametogenesis in microgravity. No defective karyotypes or cell distributions were seen and pairing, disjoining, and recombination of chromosomes were comparable to ground. There were however, a variety of mutants isolated in the *unc-22* gene and in essential genes balanced by the *eT1* translocation. These mutants isolated from regions where HZE particles were identified were more severe than from random screening. Large chromosome deletions were found among the *unc-22* mutants. The rates of mutagenesis in flown worms was significantly higher than ground controls.

The experiment of Nagaoka, et al. on SL-J evaluated the effect of cosmic HZE radiation that can easily penetrate the outer wall of the Shuttle to reach the inside, and secondary radiation generated from effects of HZE interacting with the Shuttle and payloads. Species evaluated included **corn and soybean seeds, bacteria and brine shrimp**. The soybean seeds were more sensitive than the corn seeds. *Artemia salina* eggs exposed to radiation showed that pycnosis frequency of cells of juveniles was significantly higher than the ground and *B. subtilis* plasmid measurements showed damages to plasmid DNA or to host genes about 20% difference between flight and ground. ***Drosophila melanogaster*** flown on SL-J were evaluated for HZE damage. Results showed the X chromosomes in flown flies had twice the frequency of lethal genes compared to ground controls. In the radiation sensitive strain, the mutation frequency was significantly higher than ground controls while the wild type strain showed no significant differences between flight and ground groups.

### **DNA Repair in Microgravity**

(Organisms were subjected to radiation pre-flight to test repair in microgravity). An experiment on IML-2 used *Escherichia coli*, a **human primary fibroblast** line and a strain of *E. coli*, PQ37 to test the hypothesis that increased radiation sensitivity of biological systems in microgravity is caused by effect of microgravity on cellular **repair processes**. Results showed that this is not the case. Indeed, no significant differences were found in the rejoining kinetics of radiation induced double-strand break of DNA in *E. coli* and in microgravity, intact DNA increased with increased time in space. In human skin fibroblasts the rejoining kinetics were almost identical at microgravity, and in the 1g in-flight centrifuge control and ground control. The *E. coli* strain PQ37 also repaired its DNA under all gravity conditions. The conclusions were that prokaryotes and human fibroblast cells are able to repair DNA lesions in microgravity as efficiently as on the ground and gravity is not required in the repair process. These results were corroborated by another experiment on IML-2 using *Bacillus subtilis*. The objective was to test influence of microgravity on the cellular repair process by evaluating survival of spores of *B. subtilis* in microgravity after UV-radiation pre-flight on the ground. The irradiated spores were germinated in static microgravity and in the 1g in-flight centrifuge as well as in ground controls. Results again proved that DNA repair can be initiated and function normally in microgravity.

While the results of experiments with various bacteria showed that the DNA repair process is as efficient in microgravity as in 1g, an experiment with **yeast** flown on IML-1 provides some evidence that repair in this organism may be delayed under mission conditions. Whether conditions of spaceflight or microgravity *per se* influenced repair of double strand break in yeast flown on this mission is not clear from this experiment.

# BIOMEDICAL RESEARCH AND COUNTERMEASURES

## Significant Scientific Results Summary

### 1. ANIMAL PHYSIOLOGY

Animals physiology studies flew on six of the Spacelab missions. Animal physiology experiment specific areas included bone, muscle, cardiovascular, neurophysiology, renal physiology and endocrinology, immunology, metabolism and nutrition, and chronobiology. The rat was the most studied species. Physiology of mouse, fish and avian species are also included in this section. There were more than 100 individual animal physiology experiments flown. Descriptions are given below for each of the experiment specific categories. (More detailed information is provided in the Experiments Descriptions section of the Appendix A).

#### Experiment Specific Category - BONE

Thirteen experiments to investigate effect of microgravity on bone and cartilage formation, mineralization, endocrinology, and metabolism were flown on five of the Spacelab missions. The primary animal species used for these investigations was *Rattus norvegicus* (Rat). The table below gives an overview of missions and experiments on bone in animal models.

#### ANIMAL PHYSIOLOGY - BONE

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
Spacelab 3	STS-51B	1985	7+	Mineralization of matrix Kidney function, Ca excretion Bone loss	Duke, P. J. Mangelsdorf, D. Doty, S. B.
SLS-1	STS-40	1991	9+	Calcium metabolism Bone regeneration	Kaplansky, A. S. Oganov, V. S.
IML-1	STS-42	1992	8+	Chondrogenesis	Duke, P.J.
SLS-2	STS-58	1993	14+	Histomorphometric changes Bone minerals Metabolism Bone, calcium & spaceflight Bone cell turnover and recovery Histomorphometric study	Alexandre, C. Oganov, V. S. Shigematsu, T. Morey-Holton E. Zerath, E. Durnova, G. N.
LMS	STS-78	1996	16+	Corticosteroids in bone loss	Wronski, T. J.



Skeletal loss in the long bones, primarily weight-bearing bones, is well documented yet mechanisms are not clear. Earlier experiments on Cosmos unmanned orbiting spacecraft showed that production and mineralization of bone matrix was retarded, contained fewer collagen fibers, and collagen was less mature in flown versus ground controls. The effect of microgravity on cartilage development and bone formation can result in marked skeletal changes including decrease in bone volume and altered biochemical properties. Loss of bone mass remains one of the most important biomedical concerns to long-duration human habitation of microgravity environments.

An experiment on **SL-3 (Duke)** showed that even during a short spaceflight, less **matrix** is formed and there is less mineralization in rat bones. The primary defect was at the level of initial matrix production. Compared to ground controls, flown animals had very low Na and K values, Mg levels were unaffected, and S levels were less than half of control values. Ca values were less in both mineralized and unmineralized areas of the bone samples. As a follow up to investigate production of collagen by bone primary mouse bone cells in culture was flown on **IML-1**. This experiment addressed **chondrogenesis** in skeletal development. Endochondrial ossification involves collagen synthesis as well as other factors. Using cells from hind and fore-limbs of mouse embryos, **Duke** found no significant differences in cellular nodule appearance between flight and ground samples. Flight cultures formed aggregates of cells with abnormally smooth surfaces and these showed unusual ruffled structures. Indications of chondrogenesis were evident in flight cells yet mineralized matrix did not form. Conclusions were that although chondrocytes could function, proliferation of rough endoplasmic reticulum and production of matrix did not occur in flown cells.

To investigate activity of bone forming cells, **Doty** evaluated osteoblasts from tibias of adult rats flown on **SL-3**. He found no significant differences in alkaline and acid phosphatase, Golgi activity, secretory granule size, and lysosomal activity between flight and ground controls. However flown samples had smaller cytoplasmic volume indicating possible differences in processing of protein, possibly including procollagen, in microgravity. This could result in less new bone formation. Leading to understanding of osteoporosis in space, **Oganov et al.** on **SLS-1** showed that bone regenerative potentials decreased, thus stimulating the process of osteoporosis. Based on results of previous flight experiments that showed a reduction in trabecular bone, caused by inhibition of new bone formation and increased resorption, **Durnova et al.** investigated effect of microgravity on spongy bone on **SLS-2**. (Trabecular bone is the small needle-like, flat projections of bone or scaffolding between the red and yellow bone marrow that constitute the inner part of bones). In the proximal metaphysis of tibia of rats, no changes were found in the growth plate of spongiosa in flown rats compared to ground controls. However evaluations of rats sacrificed 5 hours after landing show significant decrease in spongiosa due to reduction in trabeculae. Flight rats sacrificed 15 days post-flight had primary spongiosa volumes 23% higher and secondary spongiosa volumes 22% lower than control rats. Increased space between trabeculae resulted from decreased trabeculae. Visual examination of the tibia from animals sacrificed in flight and at 5 hours after landing showed larger numbers of osteoclasts thus high resorptive capability. In agreement with other reports, the conclusion was spaceflight causes changes which are characteristic of early stages of osteopenia.

Evaluations by weighing humeral bone from rats flown on SLS-2 by **Zerath et al.**, indicated that normal growth was unaffected by spaceflight. However flown animals exhibited inhibition of bone formation in humeral proximal metaphysis and thoracic vertebrae and a decrease in bone volume in humeral metaphysis. Samples at 14 days after flight showed that osteoblastic and osteoid surfaces had returned to normal and bone volume in humeri was normal. The static bone formation was not restored in thoracic vertebrae. The caudal vertebrae did not show differences in osteoblast cell growth for cells isolated and cultured in vitro. Thus humeri, thoracic, and caudal vertebrae showed different patterns of response and recovery. This is an important finding and confirms the fact that gravitational loading (unloading) of bones leads to differences in bone turnover rate in different bones.

A comprehensive experiment flown by **Morey-Holton et al.** on SLS-1 evaluated growth, metabolism, gut and renal involvement in calcium loss during spaceflight, and recovery of bone-related parameters post-flight. The rats remained in good condition during the mission as evidenced by normal weight gain. Post-flight changes compared to ground controls included: decrease in food consumption for about 3 days, increase in urine volume, no change in urinary matrix/mineral parameters, no change in ionic calcium or blood pH on landing day or 14 days after landing, no difference in bone length, density, mineral/matrix or biomechanics and bones grew normally throughout the experiment. No gross change in endosteal osteoblast histochemistry was found. The control showed increased alkaline phosphatase and a decrease in tartrate-resistant acid phosphatase activity at 14 days (bone differentiation enzymes) while these enzymes in flown rats did not change. The mineralization of bone at the periosteal surface of the tibia-fibula junction decreased about 15% in flown rats during flight and did not return to normal until 14 days after landing. The humerus was not affected by spaceflight. Conclusions from this research were that re-adaptation of rapidly growing rats in 1g after flight requires at least a week. Spaceflight changes in bone mineralization are related to bone site and age of the animal. Young rats appear to be extremely sensitive to gravitational loading while age-related bone loss may be influenced by a decreased sensitivity to gravitational loading.

Metabolic studies of **Kaplansky** on SLS-1 evaluated bones, blood plasma, and endocrine factors that participate in bone metabolism regulation. Limb bones and lumbar vertebrae were evaluated. Results showed decrease secondary spongiosa and increased bone resorption surface in proximal metaphyses of tibiae. These are signs of developing osteoporosis. These changes correlated with biochemical data showing decreased alkaline phosphatase activity and increased activity of tartrate-resistant acid phosphatase (a bone resorption enzyme). There were decreases in bone calcium, phosphorus, sodium and chloride and depressed function of thyroid C-cells producing calcitonin which is necessary for normal mineralization of bone matrix. Mineral metabolism changes confirmed previous findings that calcium is higher and phosphorus is lower in blood of flown animals. Somatotrophic activity was depressed in the pituitary leading to decreased synthesis and secretion of growth hormone.

Another experiment evaluating mechanisms of bone loss during spaceflight was flown on SL-3 by **Mangelsdorf et al.** The kidneys function in regulating calcium retention by a mechanism that involves 1,25-dihydroxyvitamin D<sub>3</sub>. Kidneys from five flight and five ground controls were evaluated post-flight and evaluated for 1,25-dihydroxyvitamin D<sub>3</sub> receptors. There was no

demonstrable difference qualitative or quantitative evaluation between 1,25 (OH)2D3 receptors in the kidneys of flown rats. These data suggest that these receptors do not play a vital role in regulating renal calcium excretion during spaceflight. Instead, kidneys appear to be functioning normally by excreting calcium in response to the artificially induced state of hypercalciuria (higher than normal calcium in the blood). The hypercalciuria occurs because of demineralization of bone thus regulation of calcium loss is related to bone processes and not kidney function.

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### **Experiment Specific Category - MUSCLE**

Thirteen experiments investigating muscle physiology in rats were flown on three Spacelab missions. Topics of these experiments are presented in the table below. More detailed descriptions may be found in the Appendix A. The soleus, a primary weight-bearing muscle sometimes referred to as the antigravity muscle, was the subject of several investigations. As was predicted, the soleus showed the most dramatic changes in response to microgravity. Flexor muscles such as the tibialis anterior, and extensor muscles (extensor digitorum longus) were not significantly affected by gravitational unloading in microgravity.

### **ANIMAL PHYSIOLOGY - MUSCLE**

<b>Spacelab Designation</b>	<b>STS Mission</b>	<b>Launch Year</b>	<b>Duration (days)</b>	<b>Investigation</b>	<b>Principal Investigator</b>
Spacelab 3	STS-51B	1985	7+	Rat soleus Muscle protein and glucogen	Edgerton, V. R. Henriksen, E.J.
SLS-1	STS-40	1991	9+	Contractile properties Protease activity Myosin Isoenzymes	Oganov, V. S. Riley, D. A. Hoh, J. F.Y.
SLS-2	STS-58	1993	14+	Biochemical & metabolic props. Morphology Muscle fiber proteins Morphology of muscle fibers Muscle fiber function Beta-adrenoceptors in muscle Microscopy and protease activity Histochemical & biochemical	Baldwin, K. M. Ilyina-Kakueva Kato, K Marini, J. F. Mounier, Y. Ohira, Y. Riley, D.A. Yoshioka, T.

#### **General significant findings included:**

1. Muscle atrophy occurs in microgravity but interstitial edema and sarcomere lesions appear to be related to postflight activity (Riley, SLS-2)

2. Spaceflight induced significant fiber shrinkage or atrophy and increased expression of fast muscle characteristics (fast myosin) in slow fibers. In addition muscle damage, resulting from muscle atrophy in microgravity, that occurred postflight included thrombosis of microcirculation, interstitial and cellular edema, muscle fiber fragmentation, sarcomere disruptions, activation of phagocytic cells, elevated ubiquitin conjugation suggesting protein breakdown. Accelerated aging-like involution of neuromuscular junctions was found in caged rats, thus was not just a characteristic of spaceflight. The abductor longus muscle appeared more susceptible to damage probably due to resumption of activity after flight. (Riley, SLS-1).

3. To define the size and metabolic responses to spaceflight and to determine the specificity of these responses to muscle and energy-related enzyme activity of ATPase, rat muscles were evaluated for a number of characteristics after the Spacelab-3 mission. Results showed wet weight of flight muscles significantly reduced (36% loss in soleus and 15% loss in extensor digitorum longus). The greatest relative fiber atrophy occurred in muscles with highest proportion of light ATPase fibers. An increase in the proportion of fast oxidative glycolytic fibers in some muscles at the probable expense of slow oxidative fibers was also seen. (Edgerton, V. R., SL-3)

4. The slow-twitch fibers of skeletal muscle work against gravity and it was postulated that slow-twitch antigravity muscles would be reduced after spaceflight. Microgravity affects muscle fiber type and muscle isomyosin composition. Soleus muscles in flown rats showed marked increase in proportion of fibers expressing fast type II isomyosin. In microgravity, muscle fibers changed from slow to fast but the change was not as dramatic as the tail-suspension model in 1g. Slow fibers atrophied faster than fast fibers. The hypothesis that some slow fibers convert to fast was shown by this experiment. (Hoh, Joseph, F. Y., SLS-1).

5. Since microgravity has been shown to cause changes in the slow-twitch fibers of the soleus muscle, and the density of beta-adrenoceptors (beta-AR) in the rat soleus decrease in flown rats, metabolic adaptation was tested in the rat plantaris muscle. Results showed that beta-AR was significantly reduced, due to a change in the number of receptors, after flight and did not return to normal levels at nine days post-flight. Succinate dehydrogenase activity was reduced by 24%. This returned to normal 0 days after landing. The significant conclusion was that the changes in metabolic enzymes was associated with decrease in inner membrane enzymes in the mitochondria. (Ohira, Y, SLS-2).

6. Investigation of contractile properties of skeletal muscles in rats after a 9-day flight showed that greatest changes occurred in weight-bearing soleus muscles. The changes included decrease in diameter of fibers, decrease in isometric tension, and contraction velocity. These results confirm that muscle function in flight is reduced resulting in greatest change in the weight-bearing muscles after return to earth. (Oganov, V. S. , SLS-1).

7. Even short duration spaceflight causes significant changes in contractile properties of the antigravity (slow-twitch) skeletal muscles. Myosin heavy chain phenotype and muscle mass mediate these changes.

8. Tail-suspension rats showed higher glucogen concentration in the soleus as did flown rats (see table above). Recovery from tail suspension was accompanied by decreased tyrosine whereas, flown rats showed a higher level of tyrosine indicating negative protein balance and less recovery. (Henriksen, E.J., SL-3)

Significant information on responses of specific muscle types and muscle metabolism and atrophy in rats returned after flight compared to hindlimb suspension models and ground controls was gained from experiments flown on SL-3. The muscles of the leg including the soleus, vastus intermedius, and plantaris are weight supporting muscles. These showed significant changes under conditons of gravitational unloading, whereas the muscles that primarily have a flexor activity, such as the Tibialis anterior, showed less effects. Changes that were detected in flown rats after the 7 day Spacelab 3 Mission showed muscle weight loss, changes in contraction speed, flight-related atrophy, reduced growth, and dramatic increase in glycogen indicating significant alteration in energy metabolism. This information is summarized for the individual muscle types and shown in the table below.

<u>SOME EFFECTS OF SPACEFLIGHT ON SPECIFIC MUSCLES</u>		
Muscle Studied	Effect of Spaceflight	PI (Mission)
SO Soleus	36% wet weight loss Significant decrease in mass Speed-related contraction 25% faster Flight-related atrophy Dramatic increase in glycogen Tyrosine levels greater than control	Edgerton (SL-3) Baldwin (SL-3) Baldwin (SL-3) Henriksen (SL-3) Henriksen (SL-3) Henriksen (SL-3)
PL Plantaris	Significant decrease in mass Reduced growth	Baldwin (SL-3) Henriksen (SL-3)
GN Gastrocnemius	Reduced growth	Henriksen (SL-3)
EDL Extensor digitorium longus	15% wet weight loss Reduced growth	Edgerton (SL-3) Henriksen (SL-3)
TA Tibialis anterior (flexor)	No decrease in mass No reduced growth	Baldwin (SL-3) Henriksen (SL-3)
VI Vastus intermedius	Significant decrease in mass	Baldwin (SL-3)

**Experiment Specific Category - CARDIOVASCULAR PHYSIOLOGY AND HEMATOLOGY**

The following table shows the mission information for cardiovascular and hematology experiments conducted on the Spacelab missions. Detailed experiment descriptions may be found in the Appendix A.

**CARDIOVASCULAR PHYSIOLOGY AND HEMATOLOGY**

<b>Spacelab Designation</b>	<b>STS Mission</b>	<b>Launch Year</b>	<b>Duration (days)</b>	<b>Investigation</b>	<b>Principal Investigator</b>
Spacelab 3	STS-51B	1985	7+	Spaceflight anemia Cardiac structure & AMP metab	Lange, R. D. Philpott, D. E.
SLS-1	STS-40	1991	9+	Erythropoiesis	Lange, R. D.
SLS-2	STS-58	1993	14+	Erythropoiesis Hematology/renal physiology Heart muscle adaptation Immunohistochemistry	Ichiki, A. T. Alfrey, C. P. Mironneau, C. Gabrion, J.

Human adaptation to microgravity results in loss of red blood cell (RBC) mass, reduction in plasma volume and decrease in total blood volume. Spaceflight-induced anemia is the subject of a number of investigations to discover the potential mechanisms. Use of rats as a model to investigate space adaptation responses on the Spacelab missions proved an excellent means to investigate space anemia. The first of four experiments to investigate erythropoiesis and space anemia, was flown on SL-3 by Lange, et al. This experiment demonstrated a significant increase in hematocrits (ratio of packed cells to whole blood volume), RBC counts, hemoglobins and neutrophils. (The increased cell counts could be due to artificially increased concentrations because the plasma volume was reduced in spaceflight as a result of fluids shifts and loss in microgravity). On SL-3, Lange also found a significant reduction in the percentage of lymphocytes confirming earlier reports that lymphocytes are affected by spaceflight. Bone marrow, spleen and erythropoietin (EPO), the hormone that stimulates RBC precursors in the bone marrow to development into mature RBCs, showed no significant differences between flown and ground animals. Bone marrow cells of flown rats could be induced by EPO to produce erythroid colonies, thus the changes in RBC numbers was apparently not due to faulty cell response to EPO stimulation. Alfrey, et al. also found on SLS-1 that erythropoiesis appeared to be stimulated normally in microgravity. On SLS-2, Ichiki, et al. found serum EPO levels to be the same in rats bled inflight and ground controls, but after landing, the EPO levels were significantly higher for flown rats.

Lange, et al. on SLS-1 and colleagues, Ichiki, et al., on SLS-2 further investigated spaceflight anemia and effects of microgravity on hematopoietic cells. On SLS-1 the experiment was

designed to study regulatory parameters that modulate RBC survival. Results showed a significant decrease in the number of EPO-responsive erythroid progenitor cells. This would seem to be in contrast to the SL-3 and SLS-1 results. It should be considered that differences in age of animals tested or the types of cells tested (peripheral blood versus bone marrow precursor cells) may give different results. A consistent finding in all experiments was the reduction in lymphocytes in peripheral blood. There was also a decrease in monocytes and eosinophils and an increase in the number of neutrophils.

An experiment, conducted on SLS-2, investigated **cardiovascular system adaptation** to microgravity. In humans, characteristic adaptation to upper body fluid shifts in space include increased heart rate, blood pressure and total peripheral vascular resistance, and decreased venous pressure. Upon return to Earth, re-adaptation causes severe increase in heart rate and low blood pressure. Results of the study with heart tissue removed from rats after flight on SLS-2 showed that **contractile strength** of heart muscle was decreased. There was also a reduction in specific affinity to alpha 1 adrenoreceptors indicating that reduction in contractile strength is due to a decrease in sensitivity rather than a decrease in number of the adrenoreceptors. An interesting conclusion, in light of the involvement of protein kinase C in lymphocyte activation signal transduction, was the implication of desensitization of adrenoreceptors due to microgravity may be dependent on increased protein kinase C activity. This would be an interesting research area for future mechanism studies. On SL-3, **Philpott, et al.**, investigated **cardiac deconditioning** at the level of ultrastructure and cyclic AMP. He found changes in ultrastructure and biochemistry in heart tissue of flown rats. Changes included accumulation of lipid droplets, changes in glycogen deposits and changes in microtubules. Biochemically, changes in adenylate cyclase and low KM phosphodiesterase did not differ from ground controls however; a decrease in high KM phosphodiesterase was found in flown heart tissue. Protein kinase activity decreased, adrenergic responses were affected, and intracellular signal processing of the receptor interactions was modified. Metabolic processes were also altered in microgravity.

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### Experiment Specific Category - ENDOCRINOLOGY

Experiments to determine the effects of microgravity on hormone and regulatory peptide synthesis and release have shown that spaceflight has significant effects on animal physiology. Most (12) of the animal physiology experiments were flown on the Spacelab-3 mission. One flew on SLS-1 and five endocrinology-related experiments were flown on SLS-2. A total of 18 endocrinology-related experiments were conducted on the three Spacelab missions. The table below provides information on Spacelab missions with endocrinology-related experiments.

Fluid shifts to the upper body during spaceflight is related to changes in fluid regulating hormones. Atrial natriuretic factor (ANF) is one of the hormones that regulate fluids shifts. ANF is secreted in response to increased pressure in the cardiac atria from increased shift of fluids to the upper body. ANF activates membrane-bound guanylyl cyclase coupled receptors (GC-A

receptors). A second type of guanylyl cyclase coupled receptor is an apparent target for a natriuretic peptide in the brain. A third receptor appears to be coupled to adenylyl cyclase. Other hormones including vasopressin, catecholamines, in addition to ANF regulate response to fluids shifts and rennin influences blood pressure. Atriopeptin (AP-3) is released when right atrial stretch receptors are stimulated (possibly by fluid shifts in microgravity). The atriopeptins cause natriuresis and diuresis by direct action on the kidney as well as inhibition of aldosterone and vasopressin secretion and dilation of large vessels resulting in further central pooling of blood.

## ANIMAL PHYSIOLOGY - ENDOCRINOLOGY

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
Spacelab 3	STS-51B	1985	7+	Atriopeptin (AP-3) in plasma Renin secretion Pituitary function Thyroid function Liver enzymes ANF-sensitive guanylyl cyclase ANF regulation ANF-sensitive guanylyl cyclase ANP binding sites Calcium loss/fluids balance Hypothalamus/GABA activity Salivary gland biochemistry	Inge, W.H. Hartle, D.K. Hymer, W. C. Loginov, V.I. Merrill, A.H. Gerzer, R. Gerzer, R. Gharib, C. Gharib, C. Natochin, Y.V. Krasnov, I.B. Mednieks, M.I.
SLS-1	STS-40	1991	9+	Growth hormone releasing factor	Grindeland, R.E.
SLS-2	STS-58	1993	14+	Catecholamines Brain/natriuretic peptide Stress hormones Pro-ANP and ANP Pituitary somatotrophs	Gabrion, J. Gabrion, J. Kaplansky, A.S. Gabrion, J. Alekseyev, E.I.

The following table provides some of the significant findings on effects of hormone synthesis and function in animals during spaceflight on Spacelab missions.



## DISCIPLINE CATEGORY- ANIMAL PHYSIOLOGY

### Experiment Specific Category - ENDOCRINOLOGY

Mission	PI	Species/tissue	Results microgravity versus ground
SL-3	Inge	Rat./heart	Objective: to evaluate atriopeptin (AP-3) location in plasma of spaceflown rats. Results: Demonstrated profound effect of use of halothane anesthesia. This caused 400% increase in level of AP-3 in plasma. The right and left atria had higher levels of AP-3 than control rats but the difference was not statistically different. These rats were subjected to landing stresses and this experiment demonstrated the need for obtaining samples inflight.
	Mednieks	Rat/salivary gland	Objective: to evaluate effect of spaceflight on biochemical changes in salivary gland. Salivary gland biochemistry and morphology can provide information on hormonal and environmental response, specific reactions of the oral cavity, and exocrine gland function. Catecholamines cause altered cell morphology and changes in cyclic AMP-dependent protein kinase (cA-PK) activity and cell location. Results: Endogenous protein phosphorylation increased in parotid and sublingual glands. cA-PK activity showed no significant difference in flown animals however, there was an increase in labeling of regulatory subunits in the parotid cell particulate fractions from flown animals. Cyclic AMP appears to be involved as a mediator of cA-PK association and subcellular subunit distribution.
	Hartle	Rat/ plasma	Objective: to detect alteration in renin secretion in space-flown rats. Renin secretion is regulated by cardiovascular, hormonal and neural mechanisms. Renin-angiotensin-aldosterone system affects blood pressure by promoting positive sodium balance and enhancing vasoconstrictor tone. Atriopeptin III augments shifts and promotes diuresis and natriuresis.

Results: No significant differences were found in plasma renin concentration between flight and control animals. Halothane anesthesia did not cause a significant increase in plasma renin.

Hymer	Rat/pituitary glands	<p>Objective: to evaluate release of growth hormone (GH) from pituitary glands in spaceflown rats. Preliminary results from earlier flight indicated that release of GH from cells may be impaired in microgravity.</p> <p>Results: Pituitary glands of flown rats contained two to three times more intracellular hormone than controls but released significantly less. Conclusions were that since balance between somatostatin and GH releasing hormone regulate hormone secretion, microgravity may alter this relationship to lower release rates. Previous results that release of GH will be confirmed.</p>
Loginov	Rat/thyroid glands	<p>Objective: to evaluate thyroid changes in microgravity.</p> <p>Results: Histological examination showed decrease in the size and number of type 3C-cells. There was evidence for reduced biosynthesis and secretory activity in microgravity.</p>
Merrill	Rat/liver	<p>Objective: to investigate activities of liver enzymes. Lipid metabolism is a major function of the liver and previous results of spaceflight showed changes in enzymes of lipid metabolism.</p> <p>Results: Serine palmitoyltransferase (SPT) activity was significantly lower in flown rats. Glycerol 3-phosphate acyltransferase (GPAT) activity was not significantly different. Microsomal protein of flight rats was 33% lower than controls and there was no difference in spingomyelin (SM) content. Conclusions were that this may reflect major effects due to long-chain based synthesis in glycolipids or SM changes. The changes in hepatic SM metabolism in flight suggests changes in cellular membranes in microgravity.</p>

SLS-1 cyclase	Gerzer	Rat,/liver	Objective: to study effect of weightlessness on response of ANF-sensitive guanylyl system.
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		Results: the activity of ANF-sensitive guanylyl cyclase was unaltered in tissues from animals exposed to microgravity. Conclusions, it is probable that the cellular response to circulating ANF is unaltered during space flight.
Gerzer	Rat/ liver	Objective: to determine possible alteration of ANF regulation in weightlessness. Results: ANF-sensitive guanylyl cyclase activity was unaltered indicating no apparent altered receptor subtype distribution during exposure to weightlessness.
Gharib	Rat /brain cells	Objective: to evaluate effect of spaceflight on neurological basis of endocrine regulating factors. Results: Brain stem nonadrenergi cells were tested. Vasopressin was decreased in the hypothalamus and increased in the posterior pituitary. Norepinephrine changes indicated stress reaction associated with landing (again pointing out the need to obtain tissues inflight). Results suggested that ANF may be involved in fluid electrolyte imbalances in the brain inflight.
Gharib	Rat/brain	Objectives: to determine the affinity and number of atrial natriuretic peptide (ANP) binding sites in choroid plexus and meningia or rats flown on SLS-1. Results: The number of ANP binding sites was significantly increased without significant changes in binding affinity in the third and lateral ventricles. At different sites in brain and in meningia ANP binding sites were unchanged. Binding affinity was significantly reduced in the meningia but not in choroid plexus. General conclusions, ANP is presumed to reduce cerebrospinal fluid (CSF), the number of binding sites in cerebral ventricles would lead to reduction in CSF production in microgravity while lowered affinity of ANP binding sites in meningia could relate to outflow of CSF into subarachnoidal spaces in the brain. Vasopressin was significantly increased in the posterior pituitary and decreased in the hypothalamus due to stress on landing.
Natochin	Rat/multiple tissues	Objective: to accumulate new data on calcium loss occurs during spaceflight. Results: Water and sodium content of skin and a decrease in water, sodium, and potassium content in the heart were observed. There were no changes in these parameters in other tissues. The changes probably represent adaptation to

microgravity. Fluid-electrolyte homeostasis in animal tissues returned to normal after return to 1g.

Krasnov      Rat/brain      Objective: to assess spaceflight effects on gamma-aminobutyric acid (GABA) and other enzymes in the hypothalamus.  
Results: Post-flight, glutaminase activity was decreased by 22.7% in the arcuate nucleus and 30.4% in the medial eminence of the hypothalamus. This suggests possible role of glutamate in regulation of growth hormone secretion.

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SLS-2      Alekseyev      Rat/pituitary glands      Objective: to study histological and cytokaryometric changes in somatotroph cells in flown rats. Previous flights showed progressive minimization of endocrine regulatory function and inhibition of growth hormone (GH) production and secretion.  
Results: Pituitary glands in rats sacrificed after 5 hours in flight had greater GH concentration than controls. Conclusions were that spaceflight diminishes functional activity of somatotroph cells. Back in 1g, rats recovered and this activity returned to normal.

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## Experiment Specific Category - METABOLISM AND NUTRITION

Nine experiments were flown on three Spacelab missions, SL-3, SLS-1 and SLS-2, to investigate the digestive and metabolic changes that occur during and after spaceflight. Previous experiments with animals have shown that spaceflight significantly affects metabolism. The following table provides information metabolism and nutrition of rats flown on the Spacelab missions. Detailed information is presented in experiment descriptions in the Appendix A.

### ANIMAL PHYSIOLOGY - METABOLISM AND NUTRITION

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
Spacelab 3	STS-51B	1985	7+	Hepatic enzyme adaptation	Hargrove, J.L.L.
SLS-1	STS-40	1991	9+	Exocrine function, pancreas Gastric hypersecretory syndrome Digestive transport function Microbial/epithelial tissue Metabolic potential/microflora Lipid peroxidation	Smirnov, K.V. Smirnov, K.V. Smirnov, K.V. Szylit, O Szylit, O. Popova, I.A.
SLS-2	STS-58	1993	14+	Digestive physiology Energy and structure/liver	Szylit, O Ivanova, S.M.

The Spacelab mission experiments advanced understanding of the qualitative and quantitative changes in lipid metabolism, the interactions between function of endogenous intestinal microflora and digestive function, and digestive enzyme activity and function during and after spaceflight. Metabolic breakdown of nutrients, medications, and many hormones occurs in the liver and numerous hepatic enzymes regulate catabolic function. Adaptation to spaceflight includes biochemical changes in the liver to accommodate energy requirements, including glycolysis and lipid peroxidation. **Hargrove and Jones (SLS-3)** found a 20-fold higher glycogen content in flown rats post-flight compared to ground controls. In addition, glucose levels and enzymes of the citric acid cycle were decreased and glycolysis and ATP synthesis was increased (**Ivanova et al., SLS-2**). Experiments of Popover, et al., on SLS-1 showed that spaceflight did not significantly affect the antioxidant protection component in liver and other tissues but after return to 1g, readaptation caused in changes in antioxidant protection. Endemic intestinal microflora provide enzymes that interact synergistically with the host to facilitate digestion in the small intestine. A very important finding was that lipid metabolism was greatly altered by spaceflight. Lipase activity was significantly decreased (**Smirnov, et al., SLS-1**) and short chain fatty acid concentration was significantly increased (**Szylit, et al., SLS-1 and SLS-2**) indicating a different metabolism in energy providing metabolism in microgravity. **Popova et al. (SLS-2)** concluded that changes in basic metabolism in erythrocytes and lymphocytes were due to structure and function of their membranes because lipid and phospholipid composition of the membranes was changed. This can be extremely significant to the understanding of mechanisms responsible for blunted lymphocyte

response to antigen stimulation during spaceflight. The following table further describes each of the metabolism and nutrition experiments and list most significant results for each.

## DISCIPLINE CATEGORY- ANIMAL PHYSIOLOGY

### Experiment Specific Category -Metabolism and Nutrition

Mission	PI	Species/tissue	Results microgravity versus ground
SL-3	Hargrove	Rat/liver	<p>Objective: to determine whether hepatic enzyme concentrations change during spaceflight.</p> <p>Results: Twenty-fold higher glycogen content in liver of animals post-flight than ground controls. Microsomal protein, cytochrome P-450 was reduced in flown animal tissue.. Glutathione S-transferase, tyrosine aminotransferase, and cytochrome b5 were not statistically different from ground values.</p>
SLS-1	Smirnov	Rat/pancreas	<p>Objective: to investigate biochemistry of exocrine compartments of the pancreas.</p> <p>Results: Complex changes in digestive enzymes occurred. At 9 days post-flight, amylolytic activity of the pancreas was still elevated and lipase activity was significantly decreased. Pancreatic insufficiency during spaceflight requires further study.</p>
	Smirnov	Rat/stomach	<p>Objective: to investigate mucous membrane of stomach of rats after spaceflight.</p> <p>Results: Increased peptic potential , more marked on day 9 post flight. Hypersecretory gastric syndrome was evident in flown animals. This is characterized by high activity of gastric pepsinogen-production cells and increased gastric level of hydrochloric acid. In flown animals this was correlated with increased level of gastrin, the principal physiologic activator of gastric epithelial cells.</p>
	Smirnov	Rat/duodenum jejunum, and ileum sections of small intestine	<p>Objective: to investigate morphological and biochemical changes in mucous membrane of small intestine after spaceflight.</p> <p>Results: Complex changes in enzyme activities. In protein membrane hydrolysis there was a shift of proximodistal gradient dipeptidase activity indicating a</p>

compensatory activity. Lipid digestion had a number of alterations in digestive pattern and showed a significant decrease of non-glyceridelipase activity and an increase in alkaline phosphatase activity in small intestine. No significant changes were found in carbohydrate enzymatic . The membranes and activities of the small intestine seem to be very adaptive in space and in return to 1g post-flight.

	Szylit	Rat/ intestinal microflora	Objective: to assess bacterial and endogenous metabolic potentials of intestine. Results: Slight decrease in pH and significantly enhanced total short chain fatty acid concentration. All of this was normal by 9 days post -flight. Microbial glycolytic activities were not modified by spaceflight. Mucous containing cells were increased for some mucsin . Microsomal glutathione-S-transferase was three-fold enhances in flight rats.
	Szylit	Rat/intestinal microflora	Objective: to investigate fermentation and bacterial glycolytic activities in cecal compartment of rats. Results: Spaceflight resulted in a significant increase of total short chain fatty acid concentration. Histochemical evaluations showed an increase in the mucin - containing cells. Xenobiotic metabolizing enzymes showed some changes, all were normal by 9 days post-flight. Conclusions were that spaceflight alters digestive physiology and the detoxification processes and thus affect general metabolism.
	Popova	Rat/lipid peroxidation	Objectives: to study effect of microgravity and spaceflight on lipid metabolism. Results: Spaceflight factors did not significantly affect antioxidant protection and intensity of lipid peroxidation.
SLS-2	Szylit	Rat/intestinal microflora	Objectives: to investigate intestinal microflora interactions and intestinal function. Results: Slight decrease in pH, significant enhancement of total short chain fatty acids. The microbial glycolytic activities of Beta-glucosidase Beta-galactosidase, and acetylgalactosaminidase were not altered. There was a increase in number of mucin containing cells and the specific activity of



glutathione-S-transferase in flown cells was 3 times higher than ground controls.

Ivanova

Rat/liver

Objective: to measure enzyme activities in plasma and subcellular fractions in liver.  
Results: Glucose and isocitric dehydrogenase levels were decreased, glycolysis and ATP synthesis were increased. Immediately after recovery, hypoglycemia disappeared and hyperglycemia was noted. Other changes in metabolic enzymes were found but all returned to normal values by two weeks after landing. Changes in basic metabolic parameters in Erythrocytes and lymphocytes were presumably caused by changes in the structure (lipid and phospholipid composition) and function of their membranes.

This is a very significant finding and provides insight into membrane mechanisms causing nil growth of T lymphocytes in microgravity.

## ANIMAL PHYSIOLOGY

### Experiment Specific Category -IMMUNOLOGY

Five experiments were flown on three Spacelab missions, SL-3, SLS-1 and SLS-2, to investigate immune response of rats exposed to spaceflight as shown in the table below. More detailed information is presented in the Experiment Descriptions section of the Appendix A.

### ANIMAL PHYSIOLOGY - IMMUNOLOGY

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
Spacelab 3	STS-51B	1985	7+	Interferon-gamma production Cytokine production	Gould, C.L.
SLS-1	STS-40	1991	9+	Activity of immune cells	Konstantinova, I.
SLS-2	STS-58	1993	14+	Immunity mediators Immune function Antiviral immunity	Konstantinova, I.

Results of previous experiments have demonstrated that immune system alterations occur in animals and humans as a result of spaceflight. These are detected immediately after flight and after time, appear to normalize to pre-flight function. The immune changes predominantly are manifested as decreases in proliferation and function of T lymphocytes reflected as changes in cytotoxic activity of natural killer cells and production of cytokines.

The objective of an experiment flown on **SL-3** by **Gould**, et al., was to determine if weightlessness alters **interferon-gamma** (IFN-gamma) production by **spleen cells** of flown rats. Spleens were removed post-flight and cells were suspended in growth medium in the presence of concanavalin A to induce proliferation and interferon-gamma production. The spleens of flown rats were substantially reduced in weight compared to controls and possibly because of this, the production of IFN-gamma was reduced. Seven of ten ground controls produced IFN-gamma while only one of the ten flown rat's cells produced detectable IFN-gamma. Gould suggests that a reduction in T lymphocyte number or function or stress *per se* could have caused lack of IFN-gamma production by the spleen cells of flown rats.

In experiments flown on **SLS-1** and **SLS-2** to evaluate production of **cytokines** in flown rats, **Konstantinova**, et al., found that T lymphocyte activity in rats during spaceflight was significantly decreased compared to ground controls. The cells from rats dissected immediately after landing did not grow in contrast to increased growth of cells from rats dissected 14 days post-flight. Activity of spleen natural killer cells was reduced during and after flight and returned to normal after 14 days at 1g. No significant changes in bone marrow natural killer cell activity

were found between flight and controls. Production of interleukin 1 and 2 and tumor necrosis factors alpha and beta in spleen cell cultures of flown rats was reduced. At landing, INF-alpha and gamma were diminished. In summary, cell-mediated immunity in rats was significantly suppressed during spaceflight. Konstantinova concluded that the time course of recovery of immune function after flight suggests that the changes may truly indicate a response of the immune system to spaceflight that could increase over time.

## ANIMAL PHYSIOLOGY

### Experiment Specific Category -NEUROPHYSIOLOGY

Fifteen experiments were flown on four Spacelab missions, SL-3, SLS-1, SL-J, and SLS-2, to investigate the effects of spaceflight on the brain and nervous system and general neurophysiology of animals. The following table provides information on experiment type and mission. Detailed information is presented in experiment descriptions in Appendix A.

### ANIMAL PHYSIOLOGY - NEUROPHYSIOLOGY

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
Spacelab 3	STS-51B	1985	7+	Neurotransmitter receptors CNS, functional metabolism	Miller, J.D. Murakami, D. M.
SLS-1	STS-40	1991	9+	Cytochemistry of neurons Brain morph.& histochemistry Spinal cord & dorsal root ganglion Ultrastructure, brain cortex  Neuron morphology Neuron morphology Mammalian gravity receptors	Gershtein, L.M. Krasnov, I.B. Krasnov, I.B.  Dyachkova, L.N.  Leontovich, T.A. Leontovich, T.A. Ross, M.D.
SL-J	STS-47	1992	7+	Visuo-vestibular adaptation (fish)	Mori, S.
SLS-2	STS-58	1993	14+	Nonadrenergic response Brain morphology Brain Ultrastructure Proprioceptive cerebellum Mammalian gravity receptors	Gharib, C. Krasnov, B. Krasnov, B. Krasnov, B. Ross, M.D.

Physiological systems are generally regulated by the nervous system and many of these systems have been shown to be affected by spaceflight. Temperature regulation, fluid volume and water intake, calcium metabolism and neuromuscular control of movement are all altered in the microgravity environment. Viewed as adaptations to microgravity, these functions are mediated by changes in brain neurotransmitter interactions. Spacelab experiments were designed to evaluate enzymes involved in neurotransmitter and energy metabolism, neuron morphology, brain ultrastructure, and mammalian gravity receptors. The vestibular gravity receptors (maculas) in mammals are functionally specialized structures in the inner ear. There are two components in the sensory system that report the position of the head with respect to gravity and also sense linear

acceleration but not rotational movement. Type I macular sensory hair cells are part of a highly channeled, direct circuit and type II macular hair cells sense, as well as distribute and modify, the information coming in from the sensory system. The following table presents significant information gained from the Spacelab experiments on neurophysiology and adaptation of the rat neurotransmitter system in response to time in microgravity.

## DISCIPLINE CATEGORY- ANIMAL PHYSIOLOGY

### Experiment Specific Category -Neurophysiology

Mission	PI	Species/tissue	Results and Comments
SL-3	Miller	Rat/brain	Objectives: to study neurotransmitter receptors in brains of space-flown rats. Results: Only a few receptor changes occurred in microgravity. An increase in a hippocampus receptor may reflect neuromodulation in the specific area via serotonergic neurons.
	Murakami	Rat/hypothalamus	Objective: to examine changes in the pattern of metabolic activity in the brain. Results: The drinking activity of the rats affected the cytochrome oxidase activity and soma size in the paraventricular nucleus (PVN). Rats with normal drinking patterns, showed decreased neuronal metabolism within the PVN relative to controls. Mild dehydration increased neuronal metabolism. Examination of other hypothalamic and motor system nuclei did not show obvious changes in metabolic activity.
SLS-1	Gershtein	Rat/left hemisphere	Objective: To assess spaceflight effects on neurotransmitter enzymes and energy metabolism in neurons Results: There was a decrease in monoamine oxidase activity in fibrillar structures of the 5th layer of the somatosensory cortex and the head of the caudate nucleus and acetyl cholinesterase in bodies of neurons of the caudate nucleus . Thus, significant adaptational changes in brain chemistry occurred in microgravity.
	Krasnov	Rat/spinal cord	Objectives: to evaluate spaceflight on the spinal cord and dorsal root ganglia. Results: No changes were found at landing, or nine days after, in the enzyme activity of the anterior horns of the spinal cord. A lowered cytochrom-

oxidase activity was observed in the motor neurons of the anterior horns of the spinal cord. Motor neuron hypofunction appears to be a result of spaceflight.

Lowry	Rat/visual cortex, olfactory cortex	Objectives: to assess spaceflight effects on ultrastructure in the brain cortex. Results: Changes in neuronal and glial cells suggested active restructuring post-flight. Changes in visual and olfactory cortexes were found.	
Leontovich	Rat/visual cortex	Objectives: to assess spaceflight effects on dendrite geometry and orientation. Results: Significant increase of body size of pyramidal neurons in flight animals was found. There was an increase in the length of apical dendrites in the upper layers of the visual cortex. The apical system was well developed and associative connections between various cortical compartments was possible. There was indication of restructuring of the dendrite system of the visual cortex neurons in microgravity.	
Leontovitch	Rat/medulla oblongata	Objectives: to assess spaceflight effects on orientation of dendrites . Results: There was no significant difference between flight and ground control animals with respect of dendrite geometry of the giant multipolar neurons of regions of the medulla oblongata. There was a significant difference in amount of branching of dendrites between landing and day 9 post-flight. This suggested structural rearrangement of the dendrite tree of neurons that developed during and after flight. This is reflective of adaptation to microgravity.	
Ross	Rat/maculas	Objectives: to determine effects of spaceflight on the otoconia and neuroepithelium in vestibular organs. Results: There were increased numbers of hair cells immediately after landing. Spaceflight appears to return vestibular gravity sensors so that they can function in microgravity. In addition the release of transmitter substance making the hairs more sensitive was suggested.	
SLS-2	Krasnov	Rat/brain	Objective: to examine somatosensory and visual cortex of spaceflown rats.

			Results: Electron microscopic examination of somatosensory cortex showed ultrastructural changes in the II through IV layers which suggested that a lower number of signals entered the cortex in microgravity. Microgravity induced changes were reversible but not completely at 14 days after flight.
	Krasnov	Rat/cerebellar vermis	Objectives: to study the anterior vermis, a structure that regulates antigravitational muscles, to gain understanding of adaptation of antigravity muscles in microgravity. Results: Higher cytochrome oxidase activity was found. This indicated dorsal central lobe function during flight.
	Gharib	Rat/brainstem	Objectives: to measure norepinephrine (NE) content in brainstem sympathetic cells to gain information on blood pressure regulation. Results: No significant changes in NE content were found in brainstem or kidney and heart in spaceflown animals compared to ground.
SL-J	Mori	Fish (carp) cerebellar activity	Objectives: to evaluate mechanisms of sensory conflict theory by use of fish with one otolith removed compared to normal fish. Results: The dorsal light response was used to measure fish response. Fish turn away from the light. Behavior of the normal carp supported the sensory conflict hypothesis for genesis of space motion sickness. This fish showed confused behavior peaking at day 2 and adapting to microgravity by day 4. The recovery indicates that the cerebellum may participate in recovery in microgravity. The otolith-less carp, conditioned for two months before launch to adapt to the loss of an otolith, behaved like the normal carp indicating that sensory compensation other than the vestibule may be confused by weightlessness.



## ANIMAL PHYSIOLOGY

### Experiment Specific Category - MISCELLANEOUS

This section includes experiments that did not fit other categories but provided significant information relevant to animal physiology changes in responses to spaceflight. The following table provides information on experiment type and mission. Detailed information is presented in experiment descriptions in the Appendix A.

### ANIMAL PHYSIOLOGY - MISCELLANEOUS

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
Spacelab 3	STS-51B	1985	7+	Biological rhythms Spermatogonia Microbial flora Squirrel monkey, reponse Qualification of animal facility Capabilities of the animal facility	Fuller, C.A. Philpott, D.E. Kraft, L.M. Fuller, C.A. Callahan, P.X. Fast, T. N.
SLS-1	STS-40	1991	9+	Lung tissue	West, J.B.
SLS-2	STS-58	1993	14+	Kidney homeostasis	Serova, L.V.

An experiment, flown on SL-3 by Fuller, et al., dealt with circadian timing in rats and showed that normal expression of the circadian timing system is significantly modified in microgravity. Temperature fluctuation became delayed in flight. Normal phase period pre-flight was  $23.9 \pm 2$  hours. Inflight the temperature rhythm was  $24.4 \pm 0.3$  hours. Heart rate phase rhythm was stable in flight and ground tests with a mean period of  $23.9 \pm 2$  hours. The heart rate *per se* was depressed in microgravity probably due to reduced load on the cardiovascular system.

In another experiment on SL-3, Philpott et al., studied the effects of spaceflight on spermatogonia. Twelve hours after landing, testes were removed from rats flown on SL-3. The average weight loss of testes in flown rats was 7.1% compared to controls. A count of spermatogonial cells showed a significant decrease of 7.5% in cell population number. Radiation was not considered to be sufficient to cause the reduction in cell count. Possible explanations for reduced cell number are stress from adapting to weightlessness, transportation, or other conditions of spaceflight.

The behavior of non-human primates can be useful in verifying or predicting human responses. Squirrel monkeys flown on SL-3 (Fuller) were evaluated for possible symptoms of space adaptation syndrome. Criteria for response were feeding behavior and general behavior. A

reduction in feeding behavior was noted in both of the monkeys with return to normal feeding by day four. One flight monkey showed a series of behaviors similar to flight crewmembers affected by space adaptation syndrome (SAS). This included lethargy and reticence to move around in the cage. The monkey maintained sleep posture and showed little resistance to being moved. Whether this behavior mimics SAS in humans is difficult to say. It is clear however, that monkeys undergo an adaptation to microgravity similar to other animals and humans.

# BIOMEDICAL RESEARCH AND COUNTERMEASURES

## Significant Scientific Results Summary

### 2. HUMAN PHYSIOLOGY

The Spacelab missions contributed significantly to the understanding of human physiological adaptation to the space environment and re-adaptation to 1g post-flight. Experiments addressed the areas of bone, muscle, cardiovascular and pulmonary physiology, hematology, kidney function, endocrinology, immunology, neuro-physiology, and circadian rhythm. A total of more than 50 human physiology experiments were conducted on seven of the Spacelab missions. Significant findings in each of the experiment specific categories is presented in this section.

#### Experiment Specific Category - BONE

Human bone physiology experiments were conducted on six of the Spacelab missions. The experiments addressed bone metabolism, calcium flux and mineral loss, and the hormones related to maintenance of bone. Objectives were to advance understanding and provide information on causes of bone loss and possible countermeasures to prevent this loss during spaceflight. From some of these experiments was not available at the time this document was prepared. Data available are described. Spacelab missions including bone-related experiments are shown in the table below.

#### HUMAN PHYSIOLOGY - BONE

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
SL-1	STS-9	1983	10+	Bone metabolism	Schnoes, H.K.
Spacelab D-1	61-A	1985	7+	Plasma osteocalcin	Vermeer, C.
SLS-1	STS-40	1991	9+	Mineral loss Biomechanics	Arnaud, C.D. Bakulin, A.V.
SLS-2	STS-58	1993	14+	Mineral loss	Arnaud, C.D.
SL-M	STS-71	1995	9+	Calcium metabolism	Lane, H.
LMS	STS-78	1996	16+	Bone response Bone/calcium physiology	Cann, C.E. LeBlanc, A.

Bone is a dynamic tissue that is continuously undergoing remodeling by the interactions of osteoblasts to build, and osteoclasts to destroy bony tissue. Not only does bone function in support, protection, and movement and as a reservoir for the stem cells that differentiate into cells of the immune system and blood, but bone is also a storage tissue for fat and minerals. Calcium is involved in a large number of normal cellular processes and maintenance of nervous system homeostasis and when the level of calcium is low in the bloodstream, it is recruited from bone. Deposit and release of bone calcium and minerals goes on almost continuously. Rapid loss of bone mass occurs under microgravity conditions because of the exit of calcium and other minerals. Loss of bone is one of the most important health-related concerns that could affect the well being of humans to limit future exploration of space. Due to reduced gravity and impact stress of normal walking in Earth gravity environments, bone mass and the levels of hormones that regulate calcium in the body, decrease significantly causing calcium resorption from bone into the bloodstream. The disruption of calcium metabolism and balance, while adaptive in microgravity, causes serious imbalances in the body. Bone resorption appears to begin immediately upon reaching microgravity and the increased calcium levels in the bloodstream cause higher excretion of calcium in urine and decreased absorption by the intestines. Countermeasures are not simple since increased calcium intake in microgravity could cause still more urinary excretion of calcium and increase risk of kidney stones.

Osteocalcin, a non-collagenous protein in bone is synthesized by osteoblasts and its plasma level can be used as a marker for osteoblast activity and bone metabolism. High levels of osteocalcin in the plasma usually indicate fast growing bone. An experiment on Spacelab **D-1 (Vermeer)** designed to evaluate osteocalcin in plasma from blood drawn before launch, inflight and after landing did not show significant differences in osteocalcin levels that could be attributed to flight.

On **SLS-1**, **Arnaud** et al., found that serum ionized calcium increased dramatically on flight day 2 to levels 40% above control in all crewmembers tested. This level is considered to be severe hypercalcemia. At day eight, serum ionized calcium levels remained high, 35% above normal, indicating that clinically significant hypercalcemia was maintained throughout the flight. Parathyroid hormone (PTH), released when blood levels of ionized calcium decline, decreased to about 50% of control throughout the flight. (PTH causes calcium release from bone matrix by stimulating osteoclast activity and bone resorption). The finding that PTH was decreased, biologically validated the increase in serum ionized calcium and negated the possibility the PTH caused the hypercalcemia. Serum calcium values were close to that of control values one day after landing and were no different from the control at six days post-flight. Levels of 1,25-dihydroxyvitamin D did not differ from controls on flight day two but declined by 40% by flight day eight.

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### **Experiment Specific Category - MUSCLE**

Humans were the subjects for a number of Spacelab mission investigations on muscle physiology and adaptation to microgravity. Experiments were flown on five of the missions. Information available on the internet is described in this section and additional information may be obtained from the internet later in 1999 as databases are updated. Information may also be obtained from

references cited in the Bibliography and at the end of the Experiment Descriptions in the Appendix A.

The muscular system and neural control components of the neuromuscular system are significantly affected by spaceflight. Just after launch, very rapid adaptation in motor control to hypergravity and then to microgravity must occur. Humans in space must determine their orientation without normal cues. The degradation in skeletal muscle function after time in space may be in part, an outcome of altered motor functions or how humans move in microgravity. In addition, impaired musculoskeletal function has been noted in astronauts after spaceflight. Both muscle atrophy and neuromuscular control and contractile force of individual muscle fibers may contribute to decrease in muscle strength. Data from animals flown on Spacelab-3 and Cosmos 1887 indicated that skeletal muscle atrophy predominantly affects the slow-twitch fibers in muscles of animals. In humans, the responses may be different. Experiments on Shuttle missions have shown a greater atrophy of fast-twitch fibers. Information, available in 1999, from the Spacelab mission experiments listed in the table below will provide very significant insights into muscle function adaptation during spaceflight and re-adaptation upon return to 1g.

### HUMAN PHYSIOLOGY - MUSCLE

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
SLS-1	STS-40	1991	9+	Protein metabolism	Stein, T. P.
D-2	STS-55	1993	9+	Nitrogen & protein	Fern, E.B.
SLS-2	STS-58	1993	14+	Protein metabolism	Stein, T.P.
SL-M	STS-71	1995	9+	Skeletal muscle	Feedback, D.
LMS	STS-78	1996	16+	Contractile properties Contractile properties Musculoskeletal function Single muscle fibers Muscle atrophy Skeletal muscle	Cerretelli, P. Cerretelli, P. Tesh, P. Fitts, R.H. Edgerton, V.R. DiPrampero, P.

Two experiments investigated muscle protein metabolism as a way to gain understanding of the loss of lean body mass due to muscle wasting of astronauts. Results of Fern, et al., on D-1, showed a significant increase in rate of protein oxidation inflight and at four days postflight; a significant decrease in rate of protein synthesis, breakdown or retention inflight. These parameters had not returned to preflight values at 60 days postflight. On STS-1, Stein investigated protein metabolism

and found that nitrogen balance was decreased during spaceflight. This was greatest on day one when food intake was reduced and again at the end of the mission. On flight day 8, all six subjects showed a protein synthesis rate approximately 30% higher than preflight baselines. These results were considered to be related to stress response during spaceflight.

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## **Experiment Specific Category - CARDIOVASCULAR FUNCTION**

Cardiovascular adaptation in microgravity occurs rapidly and is characterized by shift of as much as 2000 ml of fluid toward the upper body. The experiments on human subjects to evaluate cardiovascular response in microgravity were generally involved with fluids shifts, heart function and orthostatic intolerance upon return to 1g. Investigations were conducted on seven Spacelab missions and more than 26 experiments with multiple sub-investigations were achieved. The missions involved are shown in the table below. Summary information available on the internet is described in this section and additional information may be obtained from the internet (See Appendix E for website addresses) later in 1999 as databases are updated. Additional information may also be obtained from references cited in the Bibliography and at the end of the Experiment Descriptions in the Appendix A.

Given that individual differences exist, in general the description of cardiac adaptation for humans in space is similar to that described by Saekiguchi for the Japanese payload specialist on **SL-J**. Blood pressure and heart rate increased on day one and returned to normal by the third day. Astronauts generally experience decreased performance, facial edema, over swelling of the veins, and stiffness in movement early in the mission. While cardiovascular adaptation in microgravity is rapid and effective, the orthostatic intolerance that occurs after spaceflight is associated with significant dysfunction and clinically apparent orthostatic intolerance. Characteristically, some astronauts feel faint and exhibit varying degrees of disability in standing. On **D-2**, **Arbeille and Blomquist** found that maximal cardiac pump performance was maintained in space. In the upright position after flight stroke volume was reduced by about 25% and heart rate increased 35% with a parallel increase in peripheral resistance. This confirmed **SLS-1** data which showed standing heart rate after flight increased from 82 beats per minute preflight to 98 postflight and the stroke volume were decreased from 52 ml preflight to 42 ml postflight. They concluded that orthostatic intolerance may occur by diverse mechanisms. Results were corroborated by **Baisch et al.**, in experiments on **D-2** that stand tests postflight showed increased heart rates, lower stroke volumes and cardiac deconditioning. Conclusions were that lower body fluid pooling appears to be a minor contributor to postflight orthostatic intolerance and that changes in central integration mechanisms brought about by microgravity may play a larger role in orthostatic intolerance.

To understand where fluids pool in the upper body, **Kirsch et al.**, in experiments flown on **D-2** to evaluate fluid shifts within superficial tissues of the upper and lower parts of the body, found that tissue thickness decreased about 16% around the tibia and increased by 7% in the forehead. They calculated that about 410 ml of fluid leaves lower limbs and about ml accumulates in the superficial tissues of the head. After landing this is reversed. Swelling of the head decreases within three to

five days in space bout does not disappear until after landing. Draeger et al., on D-2 measured intraocular pressure to investigate fluids shifts. The intraocular pressure preflight measured about 10 mm HG whereas, immediately after entering microgravity, this pressure increased by about 100%. After four to five days on orbit, pressure declined to preflight values. Twenty minutes after landing, intraocular pressure decreased about 30% less than preflight values.

## HUMAN PHYSIOLOGY - CARDIOVASCULAR FUNCTION

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
SL-1	STS-9	1983	10+	Venous pressure Cardiovascular function	Kirsch, K.L. Scano, A.
D-1	61-A	1985	7+	Venous pressure Fluid shift/cardiac performance	Kirsch, K. L. Baisch, F.
SLS-1	STS-40	1991	9+	Autonomic cardiovascular control Cardiovascular deconditioning Cardiovascular adaptation	Eckberg, D.L. Farhi, L.E. Blomqvist, C.G.
D-2	STS-55	1993	9+	Cardiovascular regulation Leg fluid distribution Segmental fluid content & perfusion Left ventricular configuration Tonometry - intraocular pressure Cardiovascular regulation Carotid baroreceptor -cardiac reflex Gas exchange, ventilation, heart rate Tissue thickness (fluid shifts) Central venous pressure	Arbeille, P. Baisch, F.J. Baisch, F.J. Beck, L.E.J. Draeger, J. Blomqvist, C.G. Eckberg, D.L. Stegemann, J. Kirsch, K.A. Foldager, N.
SL-M	STS-71	1995	9+	Orthostatic intolerance Physiological response, descent Orthostatic tolerance, LBNP Aerobic capacity Aerobic capacity Metabolic response to exercise	Charles, J. Charles, J. Charles, J. Siconolfi, S. Mikhaylov, V. Lane, H.
SL-J	STS-47	1992	7+	Health monitoring Japanese PS LBNP countermeasure	Saekiguchi, C. Charles, J.B.
IML-2				LBNP countermeasure	Charles, J.B.

Experiments on **SL-Mir** by **Charles et al.**, showed that long duration spaceflight effects are similar to short-term exposure. Most autonomic cardiovascular adaptations occur within the first days of spaceflight. On Mir, these changes persisted for at least four months in flight. Conclusions from the SL-Mir experiments were that long-duration spaceflight did not cause higher incidence of orthostatic problems compared to shorter duration Shuttle flights. This should be confirmed with a larger test subject pool in the future flight experiences. Heart rate and blood pressure during re-entry showed a lower than expected, small increase over values seen during normal preflight and intravehicular activities.

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### **Experiment Specific Category - HEMATOLOGY AND IMMUNOLOGY**

Hematology and immunology experiments were flown on three of the Spacelab missions as shown in the following table.

<b>Spacelab Designation</b>	<b>STS Mission</b>	<b>Launch Year</b>	<b>Duration (days)</b>	<b>Investigation</b>	<b>Principal Investigator</b>
SLS-1	STS-40	1991	9+	Erythrokinetics	Alfrey, C.P.
SLS-2	STS-58	1993	14+	Erythrokinetics	Alfrey, C.P.
SL-M	STS-71	1995	9+	Metabolism of RBCs RBC mass and survival	Lane, H. Lane, H.
				Humoral immune response Peripheral mononuclear cells	Sams, C Sams, C

Hematology experiments were flown on SLS-1 and SLS-2 and SL-Mir. A consistent finding after spaceflight has been a significant reduction on red blood cell (RBC) mass. On Spacelab-1 erythropoietin, the hormone that stimulates differentiation of bone marrow stem cells to form mature into RBCs, was decreased on day 8 in flight and at landing. To evaluate erythrokinetics, **Alfrey et al.**, tested astronauts preflight, in flight and postflight on SLS-1. Three subjects were studied during flight and each had a significant decrease in RBC mass and plasma volume. Plasma volume decrease occurred on day one of flight. Erythropoietin levels decreased in the first 24 hours and remained low throughout the mission. Clearing of RBCs from circulation was similar before and during flight. The rate of dilution of prelabeled cells by new RBCs in flight was significantly decreased compared to preflight values. The rate of production of new RBCs within bone marrow was similar after one day of flight to the rate three months preflight and also the postflight values but during spaceflight, there was a reduction in the number of newly formed red blood cells in the circulation indicating a mechanism between development in the bone marrow and release into circulation.



Experiments on SL-Mir again showed a rapid decrease in total blood volume (12%) within 24 hours. This decrease in plasma volume caused an apparent increase in hematocrit compared to preflight values. Erythropoietin levels in the serum were reduced also. The release of newly produced RBCs, which is under the control of erythropoietin, was terminated immediately after entering microgravity. Lane, et al., concluded that down-regulation of RBC production during spaceflight is due to ineffective erythropoiesis resulting from decreased erythropoietin release into the serum. Additional studies on Mir 18 over longer time will be very useful. The adaptation process to microgravity with regard to RBC mass and survival represents a state of anemia which can be used to gain understanding of the mechanisms of erythropoiesis during spaceflight.

### **Experiment Specific Category - IMMUNOLOGY**

Two experiments to evaluate response of the human immune system were conducted on SL-Mir (Sams and Lesnyak, Sams and Konstantinova). Changes in immune response have been consistently found in astronauts and cosmonauts yet the mechanisms are not clearly understood and impact to health and productivity of flying long-duration missions has not been determined. The immune system involves both cell-mediated response of T-lymphocytes and the production of antibodies (humoral or blood-borne) by B-cells. B-cells are specialized white blood cells that release antibodies into the bloodstream when stimulated by infectious organisms. The T-cells to rid the body of cells infected with bacteria, viruses, fungi and parasites. Maintenance of immunity in the body occurs by a very complex cascade of molecular and cellular events involving differentiation of cells and secretion of cytokines (cellular messenger molecules) and production of immunoglobulins. One experiment on SL-Mir was designed to investigate whether antibodies are produced in response to antigen introduced by vaccination and to determine the time course of the response. This experiment is long-term beginning with STS-71 in 1995 and continuing on Shuttle-Mir missions for several years. The second experiment series was designed to determine the phenotypic alterations in circulating immune cell subpopulations during spaceflight compared to populations observed immediately after flight and to assess functional changes in the peripheral immune cells. The roles of specific cytokines including interleukin 1, interleukin 1 receptor antagonist, and interleukins 2, 6, and 10, tumor necrosis factor alpha, granulocyte/macrophage colony stimulating factor and immunoregulatory factors such as prostaglandin E2 are being evaluated to assess spaceflight-induced immune suppression.

Additional information may be accessed as it becomes available on internet websites and from references cited in the Bibliography and at the end of the Experiment Descriptions in the Appendix A.

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### **Experiment Specific Category - PULMONARY FUNCTION**

The human lung is very sensitive to gravity therefore on Earth there are large differences in gas flow, blood flow and gas exchange between upper and lower portions of the lung. On earth, pulmonary blood flow (perfusion) is greater near the bottom of the lung and becomes smaller

toward the top. Gas flow (ventilation) is distributed throughout though there are still large differences. Generally it is believed that these differences are primarily due to the pull of gravity. Comprehensive studies of pulmonary function on SLS-1 and SLS-2 and D-2 missions showed however, that much of the imbalance in lung ventilation and perfusion is maintained in microgravity. The following table shows the Spacelab missions on which pulmonary function experiments were flown.

### HUMAN PHYSIOLOGY - PULMONARY FUNCTION

Spacelab Designation	STS Mission	Launch Year	Duration (days)	Investigation	Principal Investigator
SLS-1	STS-40	1991	9+	Ventilation inhomogeneity Pulmonary function	Paive, M. West, J.B.
SLS-2	STS-58	1993	14+	Pulmonary function Single-breath tests	West, J.B. Paiva, M.
D-2	STS-55	1993	9+	Pulmonary perfusion Ventilation distribution Pulmonary perfusion	Linnarsson, L. Paiva, M Linnarsson
LMS	STS-78	1996	16+	Pulmonary function	West, J.B.

The respiratory system is highly sensitive to gravity which causes top to bottom differences in intrapleural pressure, alveolar size, ventilation and perfusion, gas exchange, and determines chest wall configuration. Significant findings from experiments evaluating pulmonary function in microgravity are shown in the following table compiled as a summary of the information available on internet websites (See Appendix E for website addresses). Additional information will become as databases are updated. Publications and additional information may be found in the experiment descriptions (Appendix A) and Bibliography Appendix D.

## DISCIPLINE CATEGORY- HUMAN PHYSIOLOGY

### Experiment Specific Category - PULMONARY FUNCTION

Mission	Date	Days	PI	Objectives and Results
SLS-1 STS-40	1991	9+	Paiva, M.	<p>Objective: to assess pulmonary ventilation.</p> <p>Results: This was the first study to report inhomogeneity of pulmonary ventilation determined by multiple-breath nitrogen washouts during sustained microgravity. Primary determinants of ventilatory inhomogeneity during tidal breathing in the upright posture are not gravitational in origin.</p>
			West, J.	<p>Objective: to determine how various aspects of pulmonary function are affected by weightlessness.</p> <p>Results: Pulmonary capillary blood volume and membrane diffusing capacity both rose significantly in microgravity and suggest that the lung is much more uniformly perfused with blood in microgravity. Lung volume changes showed functional residual capacity reduction but no decrease in vital capacity except early in the flight. Surprising reduction in residual volume probably due to reduction in gravitational deformation of the lung in microgravity. Decrease in resting tidal volume suggests changes in neurological control of breathing.</p>
D-2 STS-55	1993	9+	Paiva	<p>Objective: to analyze chest wall mechanics and continue studies on lung ventilation.</p> <p>Results: Confirmed finding of SLS-1 that most of the ventilation inhomogeneity in the lungs does not depend on gravity related factors.</p>
			Linnarsson	<p>Objective: to investigate pulmonary perfusion homogeneous distribution in space</p> <p>Results: Data suggest the microgravity does not altogether abolish perfusion inequalities in the lung. Conclusions, factors unrelated to gravity play an important role in determining distribution of pulmonary perfusion.</p>

## Experiment Specific Category -KIDNEY FUNCTION

The following table shows the Spacelab missions on which kidney function experiments were flown.

### HUMAN PHYSIOLOGY - KIDNEY FUNCTION

<b>Spacelab Designation</b>	<b>STS Mission</b>	<b>Launch Year</b>	<b>Duration (days)</b>	<b>Investigation</b>	<b>Principal Investigator</b>
SLS-1	STS-40	1991	9+	Fluid-electrolyte regulation	Leach-Huntoon
SLS-2	STS-58	1993	14+	Fluid-electrolyte regulation	Leach-Huntoon
SL-J	STS-47	1992	7+	Endocrine changes	Seo, H.
D-2	STS-55	1993	9+	Fluid balance and kidney function	Norsk, P.
SL-Mir	STS-71	1995	9+**	Fluid and electrolyte homeostasis Renal stone risk assessment	Lane, H. Whitson, P.A.

\*\* Launched on STS-71 but continuing on Mir long-term.

Information from humans in space indicates that an increase in central blood volume leads to increased renal output of sodium and fluid and a consequent decrease in extracellular fluid volume. Early in the flights, astronauts loose 2 to 4 Kg of body mass, mostly due to extracellular fluid volume loss. The objective of experiments flown on SLS-1 and SLS-2 by Leach-Huntoon, et al., was to gain further understanding of adaptive changes that alter fluid, electrolyte, renal and circulatory status of humans in microgravity. Preliminary results indicate that glomerular filtration rate was elevated inflight especially on flight day 8. Plasma volume was 22% lower than preflight and extracellular fluid volume was 15% below preflight value and was still low at day 8. Fluid intake and urine volume decreased sharply and mean intake remained at least 20% below preflight values throughout the mission. Plasma levels of aldosterone were reduced 60% on day 1 and 28 % on day 8 and ANP was reduced 22% and 60% on day 1 and 8 respectively. Cortisol levels increased during flight. The difference between potassium intake and urinary excretion of potassium was 191% more negative on day 1 and only 39% more negative on day 2 compared to preflight. Serum potassium remained at least 20% elevated. Norepinephrine in plasma and urine was reduced by 17% at all sampling times. Urinary epinephrine decreased 80% between day 1 and 2. Most of the changes occurred early in the mission but some were prolonged including hematocrit, serum osmolality and sodium, epinephrine, angiotensin I, and cortisol.

The objective of an experiment flown on D-2 by Norst , et al., was to investigate the endocrine and renal mechanisms of fluid volume control and how humans adapt to microgravity by challenging the system with an intravenous isotonic saline infusion. In ground-based tests, the test parameters were measured on subjects in two body positions, supine and seated. The hormones that affect fluid balance and kidney function include vasopressin, norepinephrine,

epinephrine, atrial natriuretic peptide, adrenocorticotrophin, cortisol, aldosterone, and active renin. Results from D-2 showed that renal sodium excretion was doubled 2 to 3 hours after test initiation in microgravity. This compared with the values for seated subjects on the ground but was blunted during the first hour compared with supine positioned test subjects on the ground. Norepinephrine levels were highest at 3 hours. Levels of aldosterone and renin were similar to those of seated ground subjects. These data indicate that microgravity-adapted renal responses to infusion reflected a condition between ground based seated and supine subjects. The elevated norepinephrine, renin, and aldosterone levels inflight were not related to renal sodium excretion and urinary output rate.

Although short-term effects of microgravity on fluid and electrolyte homeostasis are known from experience of humans flying on the Shuttle, the long-term effects are not yet defined. SL-Mir provides an excellent means to investigate homeostasis regulating factors long-term in microgravity. Lane and Grigoriev investigated the role of the kidneys in regulation of fluid and electrolyte excretion and retention on SL-Mir. Data showed the expected plasma volume decrease averaging 5% during Mir 18. Extracellular fluid was reduced from 19.5 to 15.6 liters. These values are similar to those from a 14 day Shuttle mission. Conclusions are that changes in fluid volume that occur early in a flight, remain throughout long-term missions. Levels of two hormones important for fluid and electrolyte homeostasis (antidiuretic hormone and atrial natriuretic peptide) were reduced after 110 days of spaceflight.

Factors predisposing humans to increased risk of renal stones include excretion and negative calcium balance as a result of bone mineral loss, decreased urinary output after the first few days in microgravity, urinary pH changes, magnesium and citrate concentrations and increased urinary phosphate. These changes all can increase urinary supersaturation of stone-forming salts. Seventy percent of the renal stones in humans on Earth are composed of calcium oxalate and the remaining 39% are uric acid, struvite and cystine stones. Studies from Shuttle missions of 4 to 14 days on a total of 150 astronauts showed that immediately after flight, urine of most crewmembers is saturated with stone-forming salts placing them at risk of developing calcium oxalate and uric acid stones. There was also a difference in stone-forming salt concentrations between the short-and long-duration missions. Studies on SL-Mir (Whitson) and continuing long-term on Mir are designed to further investigate the effect of long-term habitation in microgravity on risk of development of kidney stones.

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### **Experiment Specific Category -NEUROPHYSIOLOGY**

Space motion sickness affects approximately 50% to 75% of Shuttle crewmembers in gradations of severity and presents a problem early in short-duration missions especially when the workload is heavy. It is important to understand the threshold for perception of vestibular inputs in order to improve methods for prevention, prediction and treatment of space motion sickness. This section addresses the areas of perception of gravity stimulus, posture, movement and locomotion, vestibular response, and circadian patterns. Results from the Spacelab Neurolab Mission are not currently

available and will be appearing in the literature and internet websites increasingly over the next months and years. Neurophysiology experiments were flown on seven Spacelab missions and more than 18 individual experiments have been conducted.

The following table shows the neurophysiology experiments flown Spacelab missions.

### HUMAN PHYSIOLOGY - NEUROPHYSIOLOGY

<u>Spacelab Designation</u>	<u>STS Mission</u>	<u>Launch Year</u>	<u>Duration (days)</u>	<u>Investigation</u>	<u>Principal Investigator</u>
SL-1	STS-9	1983	10+	Vestibular reactions and sensations Mass discrimination (short-term) Mass discrimination (prolonged) Eye movements during sleep	von Baumgarten Ross, H.E. Ross, H.E. Quadens, O.
SL-3	STS-51B	1985	7+	Autogenic feedback effectiveness	Cowings, P.S.
D-1	STS-61A	1985	7+	European vestibular experiments Vestibular adaptation Inversion illusions & space sickness Mass discrimination Spatial description Arm positioning	von Baumgarten Young, L.R. Mittelstaedt, H. Ross, H.E. Friederici Veringa
SLS-1	STS-40	1991	9+	Vestibular experiments on Spacelab	Young, R.
IML-1	STS-42	1992	8+	Vestibular investigations	Reschke, M.F.
LMS	STS-78	1996	16+	Canal and otolith integration Torso rotation Circadian Rhythms	Reschke, M.F. Douglas, G.D. Monk, T.
SL-Mir	STS-71	1995	9+**	Postural equilibrium Anticipatory postural activity Biomechanics of movement	Paloski, W. Layne, C. Bloomberg, J.

\*\* Launched on STS-71 but continuing on Mir long-term.

#### Vestibular responses and Space Adaptation Syndrome

To explore the full range of neuro-vestibular adaptation, a series of experiments were conducted on SLS-1 by Young, et al.. Evaluations were conducted for: 1) visually induced roll/visual-vestibular interaction. Visually-induced feelings of self-motion are normally inhibited if vestibular signals fail to confirm self motion; 2) vestibulo-ocular reflex. The angular vestibulo-ocular reflex

was tested using a rotating chair. This reflex is affected by otolith input. In microgravity, the otolith is not stimulated; 3) awareness of position. Knowledge of limb and body position may be altered in microgravity; 4) responses to linear acceleration. The sled was used to test the response of linear acceleration sensors; 5) postflight postural instability and muscle fatigue; 6) space motion sickness recording. Crew was trained to log motion sickness symptoms according to a well-being scale. Motion sickness susceptibility was measured using a head movement comparison test.

Results were as follows:

- use of visual cues was variable and depended on the individual
- after flight all subjects showed an increase in postural instability and a strong tendency to sway when the visual field rotated.
- no consistent vestibulo-ocular reflex changes were noted on orbit.
- in awareness of position tests inflight, pointing accuracy was very poor. The bias was toward pointing low. Performance was always better with eyes closed only while pointing. In this case results were similar to ground. Recovery to preflight accuracy returned by 7 days postflight. This shows that primary adaptation in microgravity is loss of the external spatial map and complete recovery requires several days after flight.
- muscle fatigue showed that isometric muscle strength was reduced by 10% to 50% postflight in ankle plantarflexion and unchanged in dorsiflexion. The fatigability did not return to baseline by day 7 postflight.

Data from two experiments flown on **D-1** provided significant information on vestibular reactions in microgravity. The experiments of von **Baumgarten** on D-1 showed the following:

- Non-thermoconvective nystagmus (eye movements) was confirmed.
- The threshold for perception of direction of linear acceleration was not significantly changed.
- A marked decrease in ocular counterrolling gain occurred immediately after reentry but recovered.
- Susceptibility to space motion sickness (SMS) was not predictable based on ground tests.
- After day 3, SMS dropped and remained low thereafter.

An experiment flown on **D-1** by **Mittelstaedt and Glasauer** investigated inversion illusions (perceiving oneself and the room to upside down despite being upright relative to a familiar room). This phenomenon is not well understood. In ground based studies, sixty control individual and five astronauts participated and motion sickness symptoms were noted as levels of discomfort. Inflight results showed:

- postural bias was negatively correlated with discomfort. (Crewmembers became sick without regard to position of the body in the spacecraft).
- sensations of trunk tilt and respective concomitant reflexes are missing in microgravity when the head is tilted with respect to the trunk.
- perception of vertical polarity persists in absence of or in contradiction to vertical position indicating existence of force-independent components in determination of vertical position.

- the overall conclusion is that saccular bias toward the Z axis may be the main determinant in the cue-free inversion illusion process.

One experiment, flown on SL-3 by Cowings, et al., investigated the effect of autogenic feedback (motion tolerance, autonomic control) as a countermeasure for space motion sickness found that it was effective for controlling space motion sickness in some but not all crewmembers. Individual autonomic response to spaceflight was different from ground simulation tests.

### **Gravity perception**

In microgravity, gravitational cues are effectively absent except for inertial cues which could be perceived by mass. Ross et al., devised an experiment on SL-1 to investigate mass discrimination by use of weighted balls and cards. Results showed that thresholds for mass discrimination in microgravity were higher by a factor of about 1.8 than preflight. Discrimination was impaired still at nine days inflight. These results suggest that humans are less sensitive to inertial mass than to weight and that adaptation can only partially compensate for loss of gravity. Ross also found in mass discrimination tests that weight perception inflight was almost half that of ground perception. Discrimination remained impaired during the flight and for two or three days after landing. These findings were confirmed and expanded on D-1 to show that normally on the ground, arm movement is slow during weight judgments while fast movements may interfere with static weight perception. Inflight results were opposite and error percentages were greater.

Friederidi studied relevance of gravity to spatial coordinate assignment and mental representation of space and spatial relations on D-1. In preflight tests errors were less than 10% and mean reaction time was normal. Inflight, both subjects found naming spatial relationships more demanding but spatial relations are adequately described in microgravity and adaptation facilitates this.

### **Locomotion**

U.S. and Russian space travelers experience locomotor and postural equilibrium disturbances often after spaceflight. Preliminary findings of Bloomberg's evaluations of astronaut locomotion on SL-Mir showed significant alteration in head-trunk coordination after long-duration flight. Astronauts appeared to have adopted a head-on-trunk locking movement by turning head and upper body at once. This head-trunk coordination disrupts gaze stabilization during locomotion. Also coordination patterns of muscle activation for lower limb muscles was altered postflight. Evaluations of Layne et al., of SL-Mir crewmembers indicated that reaction time of muscles and the sway (while standing) increased in some individuals shortly after return to Earth. Addition of foot pressure in microgravity as a countermeasure may retard muscle atrophy and maintain function of neuromuscular reflexes.

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## **OVERVIEW OF NEUROLAB, STS-90**

(NOTE: Results of the Neurolab experiments are not included in this summary. Results should become available in the Spring of 1999). An experiments list for all missions including Neurolab is given in Appendix B.



Supported by NASA, international space agencies and domestic partners, the Neurolab mission, which launched on April 17, 1998, was a dedicated 16 day life sciences mission that focused on neuroscience research. Neurolab's international partners are CSA (Canadian Space Agency), ESA (European Space Agency), CNES (French Space Agency), DARA (German Space Agency) and NASDA (Japanese Space Agency); domestic partners include several institutes at the National Institutes of Health (NIH) including the Division of Research Grants; the National Institute on Aging; the National Institute on Deafness, and other Communication Disorders; National Heart, Lung, and Blood Institute; National Institute on Neurological Disorders and Strokes; the National Science Foundation and the Office of Naval Research. Funding and development of equipment and experiment hardware for the Neurolab mission was shared between all partners.

Neurolab used the pressurized laboratory module called Spacelab, which was placed in the cargo bay of the Space Shuttle, to conduct life sciences experiments. The goals and objectives of the Neurolab mission were: 1) to use the unique environment of space flight to study fundamental neurobiological processes; 2) to increase the understanding of the mechanisms responsible for neurologic and behavioral changes that occur in space flight; 3) to further life sciences goals in support of human space flight; and 4) to apply results from space studies to the health, well-being, and economic benefits of people on Earth.

The Neurolab science payload was organized into eight science teams; each principal investigator was assigned to one of these teams. Johnson Space Center monitored the human life sciences teams: Autonomic Nervous System, Sensory Motor and Performance, Sleep and Vestibular, while Ames Research Center monitored the four animal life sciences teams: Aquatic, Adult Neuronal Plasticity, Mammalian Development and Neurobiology. The philosophy of team development was to merge complimentary scientific objectives to enhance data collection, and to share data collection, procedures, subjects, facilities and/or analysis of results.

Autonomic Nervous System investigations studied the effects of microgravity on the autonomic nervous system (ANS), specifically on its role in cardiovascular regulation. In order to monitor the sympathetic response to various ANS stressors and determine the effect of microgravity on the ANS, measurements of muscle sympathetic nerve activity, lower body negative pressure, plasma volume, blood pressure, cardiac performance by electrocardiogram (ECG) recordings, and metabolite levels were taken.

The Sensory and Performance Team examined the effects of space flight on sensory-motor function, performance and perception. Several tests were developed to examine the coordination between vision and motor activity during acclimation to microgravity, the compensation for movement in near-weightlessness, and the after-effects upon return to Earth.

The Sleep Team evaluated the normal sleep patterns of crew members before, during and after space flight to identify factors which may be contributing to sleep disturbances in space. Sleep experiments were performed to examine whether microgravity contributes to the alterations in sleep patterns. Scientists also investigated the use of melatonin as a hypnotic agent for the

treatment of sleep disturbances and the improvement of mood and cognitive performance of the crewmembers. Respiratory function and its relationship to sleep patterns was also investigated.

The Vestibular System regulates and maintains the equilibrium, or balance, of the body. Scientists attempted to determine how the Vestibular System reacts to microgravity. The Vestibular Team measured eye movements and perception of astronauts during artificial linear acceleration to determine how spatial orientation of the vestibulo-ocular reflex and optokinetic responses were altered in microgravity.

The Aquatic Team studied the afferent and efferent responses of the otoliths in Toadfish in response to linear stimuli, before, during and after space flight. The team also studied the development and formation of the gravity-sensing apparatus in fresh water snails and sword tail fish, both of which underwent significant portions of their embryonic and larval development in flight.

The Adult Neuronal Plasticity Team examined the neural and physiological changes during and following space flight to address the response in the adult Central Nervous System to altered gravity. Three critical areas of neural adaptation were examined: vestibular and motor plasticity, circadian and sleep/wake physiology and anatomy, and homeostatic regulation.

The Mammalian Development Team investigated the effects of space flight on the development of the mammalian nervous system. The development of the autonomic nervous system (ANS) and neuromuscular system was carefully studied and measured so that differences in neurological development in space versus that on Earth can be determined.

The Neurobiology Team researched the role that gravity plays in specifying the pathways through which nerves send signals throughout the body. Scientists examined the sensory neurons which are controlled by genetic and environmental cues in both the development and regeneration of gravity sensing systems in crickets.

The Neurolab mission encompassed many areas of neuroscience research and allowed in-depth study of several species in space.

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This information was provided by, and is available on the Internet from the following source:  
JSC Life Sciences Data Archive (Website address, Appendix E)

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## **OVERVIEW OF SPACELAB-MIR (STS-71)**

Spacelab-Mir (SL-M) was the first of many joint ventures between NASA and the Russian Space Agency that would begin the NASA/Mir flight program. It began during late June 1995 when the Space Shuttle, carrying a Spacelab Module and an external airlock and docking mechanism, rendezvoused and docked with the Russian Mir Space Station. Astronaut Norm Thagard had

already arrived by way of the Russian Soyuz vehicle and conducted a long-duration mission aboard the Mir. Then, while the Space Shuttle was docked to the Mir, the Mir 18 crew (Norm Thagard and two cosmonauts) was replaced with two cosmonauts (the Mir 19 crew) who were transported to orbit on board the Space Shuttle.

During the Spacelab-Mir mission, emphasis was placed on life sciences investigations. This included an evaluation of the Russian science research program which aims to counter the effects of long-duration stays in space. Retrieval of experiment samples and data from the joint 115-day Mir 18 mission was performed during SL-M, along with planned science data collection in the Spacelab. The science investigations were divided into seven general areas of study: Metabolism, Cardiovascular Studies, Neuroscience, Hygiene, Sanitation, and Radiation, Behavior and Performance, Fundamental Biology, and Microgravity Materials Science.

### **Objectives**

#### **General science objectives of the SL-M mission were:**

- To obtain engineering and operational experience in conducting research on an orbital space station.
- To develop a profile of the Mir environment as it relates to microgravity and life sciences research to help understand past and future investigations.
- To conduct specific investigations in medical support, life sciences, fundamental biology, microgravity sciences, Earth observations, and life support technology.

#### **Specific science objectives for the SL-M mission will be:**

- To transfer data and samples collected during the 115-day Mir 18 mission to the Space Shuttle.
- To collect data and samples from the long-duration crew member during the docked phase, which will complete the science program.
- To compare US and Russian hardware and protocols within the same investigation to obtain a mutual understanding of each partner's scientific approach and equipment.
- To obtain postflight life sciences data from the long duration crew member.

### **Participation**

Several NASA centers and organizations were involved in the development of the SL-M payload. Teams were composed of individuals from the Johnson Space Center, Ames Research Center, Lewis Research Center, and Marshall Space Flight Center. Each investigation had a co-investigator from one of several institutions in Russia.

This information was provided on the Internet: (Website address, Appendix E).  
JSC Life Sciences Data Archive Shuttle-Mir Web site

# ADVANCED HUMAN SUPPORT TECHNOLOGY

## Significant Scientific Results Summary

### 1. HUMAN FACTORS

Human factors include all of the factors across the disciplines that impinge on the health, performance, safety, and well-being of humans in orbiting spacecraft, planetary bases and space stations. Experiments flown on Spacelab missions in the areas of air and water quality and cognitive performance are shown in the table below.

<u>Spacelab Designation</u>	<u>STS Mission</u>	<u>Launch Year</u>	<u>Duration (days)</u>	<u>Investigation</u>	<u>Principal Investigator</u>
IML-1	STS-42	1992	8+	Mental workload	Alexander, H.L.
IML-2	STS-65	1994	14+	Microbial air sampler	Pierson, D.
SL-M	STS-71	1995	9+	Trace chemical (air quality) Trace chemical (water quality) Microbial investigation Viral reactivation	James, J. Sauer, R. Pierson, D. Pierson, D.
LMS	STS-78	1996	16+	Cognitive performance	Schiflett, S.

#### Environmental contaminants

Microbial evaluation of the crew, air, surfaces and water on the Mir Station is critical to understanding the ecology of microbial organisms that inhabit crew living areas. Based on findings over the past 25 years it is evident that microbial ecology on spacecraft undergo quantitative and qualitative changes. Investigations by Pierson et al., on microbial biota from SL-Mir provide information on incidence and mechanisms of microbial transmission between crewmembers and work station/crew transmissions. Isolations of organisms from air, water and surfaces were shown to be within the International Space Station acceptability limits.

The environment of spacecraft contain chemical contaminants that can be potential threats to crew health and safety especially on long-duration missions, These airborne pollutants must be identified and controlled and air must be scrubbed and rendered compliant with safe levels. Evaluations of air quality are a significant part of the human factors considerations. Studies of Pierson, James, and others address air quality on the Mir station.

On Mir, approximately 50% of the potable water supplied to crewmembers is produced by direct recycling of water from humidity condensate. The other primary source is from potable water delivered by re-supply spacecraft from the ground or from fuel cell water that is transferred form

the Shuttle. Experiments to assess the reliability of the water supply system are done to support future water requirements for future International Space Station needs based on information from Mir. Water samples collected on Mir 18 mission and on the STS-771 Shuttle mission were analyzed and considered to be of general potable water quality although it exceeded water quality standards for total organic carbon (TOC). Ground supplied water was considered of general potable water quality although it exceeded standards for TOC , turbidity and chloroform. These investigations are ongoing and modifications are considered for future flights.

**Microgravity environment effects on cognitive performance of humans.**

Space travelers are subjected to a number of stresses during spaceflight. These include physical isolation, confinement, lack of privacy, fatigue and changing work/rest cycles. Studies on Earth have shown that changing work/rest cycles can degrade cognitive performance and productivity. Based on the hypothesis of some scientists that performance will be less optimal in space, Schiflett et al., have designed experiments to determine the effect of microgravity on cognitive skills critical to the success of operational tasks in space. The tests include a number of cognitive, mood, fatigue, memory and performance tests. More information will be available as data are compiled for these tests.



**Appendix A:  
Investigators and Experiments**

<b>Mission</b>	<b>Investigators</b>	<b>Experiment Title</b>
STS-2/ OSTA-1	<ul style="list-style-type: none"> <li>Brown, A.H.; Chapman, D.K.</li> </ul>	<ul style="list-style-type: none"> <li>Biocompatibility of plant culture methods in a microgravity environment.</li> </ul>
STS-3/OSS-1	<ul style="list-style-type: none"> <li>Cowles, J. R.; Lemay, R.; Peterson, C.; Scheld, H. W.</li> <li>Krikorian, Abraham D.; Cowles, J. R.; O'Connor, S. A.; Scheld, H.W.</li> <li>Slocum, R. D.; Galston, A. W.; Gaynor, J. J.; Krikorian, Abraham D.</li> </ul>	<ul style="list-style-type: none"> <li>The Influence of Weightlessness on Lignification in Developing Plant Seedlings (OSS-1.1)</li> <li>Karyological Observations in Developing Root Seedlings (OSS-1.2)</li> <li>Cytological and Ultrastructural Studies on Root Tissues (OSS-1.3)</li> </ul>
STS-9/ Spacelab 1	<ul style="list-style-type: none"> <li>Baumgarten, von R.</li> <li>Brown, Allan H.</li> <li>Cogoli, A.</li> <li>Horneck, G.</li> <li>Kirsch, K.A.</li> <li>Kranz, A.R.; Buecker, H.</li> <li>Leach-Huntoon, Carolyn S.</li> <li>Quadens, O.</li> <li>Reitz, G.</li> <li>Reschke, Millard F.</li> <li>Ross, H.; Brodie, E.; Benson A.</li> <li>Ross, H.E.</li> <li>Scano, A.; Rispoli, E.; Strollo F.; Cama G.; Guidetti L.; Brazzoduro G.</li> <li>Shopper, E.</li> <li>Sulzman, Frank M.</li> <li>Voss, Edward W., Jr.</li> <li>Young, Laurence R.</li> </ul>	<ul style="list-style-type: none"> <li>Effects of Rectilinear Acceleration, Optokinetic and Caloric Stimulation on Human Vestibular Reactions and Sensations</li> <li>Nutation of Helianthus Annuus in a Microgravity Environment (1NS101)</li> <li>Effects of weightlessness on lymphocyte proliferation</li> <li>Microorganisms</li> <li>Venous Pressure</li> <li>Effects of radiation and microgravity on plant systems</li> <li>The Influence of Space flight on Erythrokinetics in Man (1NS103)</li> <li>Eye Movements During Sleep</li> <li>Radiobiology mapping: advanced biostack experiment</li> <li>Vestibulo-Spinal Reflex Mechanisms (1NS104)</li> <li>Mass Discrimination during Prolonged Weightlessness</li> <li>Mass Discrimination During Weightlessness</li> <li>Ballistocardiography in weightlessness (Exp. 1ES-028)</li> <li>Radiation measurement aboard Spacelab 1</li> <li>Preliminary Characterization of Persisting Circadian Rhythms During Spaceflight: Neurospora as a Model System (1NS007)</li> <li>Effects of Prolonged Weightlessness on the Humoral Immune Response of Humans (1NS105)</li> <li>Vestibular Experiments (1NS102)</li> </ul>
STS-51F/ Spacelab 2	<ul style="list-style-type: none"> <li>Cowles, J. R.; Jahns, Gary C.; Lemay, R.</li> <li>Schnoes, Heinrich K.</li> </ul>	<ul style="list-style-type: none"> <li>Gravity-Induced Lignification in Higher Plants (SL2-1)</li> <li>Vitamin D Metabolites and Bone Demineralization (LS-1)</li> </ul>
STS-51B/ Spacelab 3	<ul style="list-style-type: none"> <li>Callahan, Paul X.; Berry, William E.; Fast, Tom N.; Funk, Glenn A.; Grindeland, Richard E.; Lencki, Walter A.; Schatte, Christopher.</li> <li>Cowings, Patricia S.; Kamiya, Joe; Miller, Neal E.; Sharp, Joseph C.; Toscano, William B.</li> <li>Doty, Stephen B.</li> <li>Duke, Pauline Jackie; Campbell, Marion; Janer, Liliana; Montufar-Solis, D.; Morrow, Jennifer.</li> <li>Edgerton, V. Reginald; Grindeland, Richard E.; Martin, Thomas P.</li> </ul>	<ul style="list-style-type: none"> <li>Animal Studies on Spacelab-3 (SL3 1.1)</li> <li>Autogenic Feedback Training (178195 1/3)</li> <li>Morphologic and Histochemical Studies of Bone Cells from SL-3 Rats (SL3 BSP9)</li> <li>Microprobe Analyses of Epiphyseal Plates from Spacelab 3 Rats (SL3 BSP7)</li> <li>The Influence of Space Flight on the Rat Soleus (SL3 BSP5)</li> </ul>



<p>STS-51B/ Spacelab 3</p>	<ul style="list-style-type: none"> <li>• Fast, T.N.; Chee, O.; Dalton, B. P.; Grindeland, R. E.; Keil, L. C.; Kraft, L. M.; Lundgren, P. R.; Patterson-Buckendahl, P.; Reilly, T.; Ruder, M.; Scibetta, S.; Tremor, J.W.; Vasques, Marilyn.</li> <li>• Fuller, Charles A.</li> <li>• Fuller, Charles A.</li> <li>• Gould, Cheryl L.; Mandel, A. D.; Sonnenfeld, G.; Williams, Jo Ann.</li> <li>• Gould, Cheryl L.; Lyte, Mark; Sonnenfeld, G.; Williams, Jo Ann. Hargrove, James L. L.; Jones, Dean P.</li> <li>• Hartle, Diane K.; Inge, Walter H.</li> <li>• Henriksen, Erik J.; Cook, Paul H.; Jacob, Stephen; Tischler, Marc E.</li> <li>• Hymer, Wesley C.; Farrington, M.; Fast, Tom N.; Grindeland, Richard E.; Hayes, C.; Motter, K.; Patil, L. Inge, Walter H.; Hartle, Diane K.</li> <li>• Kraft, Lisbeth M.</li> <li>• Lange, Robert D.; Andrews, Richard B.; Dunn, C. D. R.; Gibson, L. A.; Jones, J. B.; Wright, Paul.</li> <li>• Mangelsdorf, David J.; Haussler, Mark R.; Marion, Samuel L.; Pike, J. Wesley.</li> <li>• Mednieks, Maija I.; Hand, Arthur R.</li> <li>• Merrill, Alfred H.; Hargrove, James L. L.; Wang, Elaine.</li> <li>• Miller, J. D.; Fuller, Charles A.; McConnaughey, Mona; McMillen, B. A.; Murakami, D. M.; Williams, H. L.</li> <li>• Murakami, D. M.; Fuller, Charles A.; Miller, J. D.</li> <li>• Patterson-Buckendahl, Patricia; Arnaud, Sara B.; Cann, Christopher E.; Grindeland, R. E.; Martin, R. Bruce.</li> <li>• Philpott, Delbert E.; Black, Samuel; Corbett, Robert L.; Sapp, Walter; Stevenson, James H.; Williams, C. S.</li> <li>• Philpott, Delbert E.; Cheng, L.; Egnor, R.; Fine, A.; Kato, Katharine H.; Mednieks, Maija I.</li> <li>• Riley, Danny A.; Bain, J. L. W.; Ellis, Stanley; Satyanarayana, T.; Sedlak, F. R.; Slocum, G. R.</li> </ul>	<ul style="list-style-type: none"> <li>• Rat Maintenance in the Research Animal Holding Facility During the Flight of Spacelab 3 (SL3 1.2)</li> <li>• Early Adaptation to Altered Gravitational Environments in the Squirrel Monkey (SL3 BSP29)</li> <li>• Homeostasis and Biological Rhythms in the Rat During Spaceflight (SL3 BSP28)</li> <li>• Effect of Flight in Mission SL-3 on Interferon-Gamma Production By Rats (SL3 BSP4.1)</li> <li>• Effect of Flight in Mission SL-3 on Cytokine Production By Rats (SL3 BSP4)</li> <li>• Hepatic Enzyme Adaption in Rats after Spaceflight (SL3 BSP24)</li> <li>• Plasma Renin Concentrations of Rats Orbited for 7 Days Aboard NASA Spacelab 3 (SL3 BSP25)</li> <li>• Muscle Protein and Glycogen Responses to Recovery from Hypogravity and Unloading by Tail-Cast Suspension (SL3 BSP12)</li> <li>• Microgravity Associated Changes in Pituitary Growth Hormone (GH) Cells Prepared from Rats Flown on Spacelab 3 (SL3 BSP27)</li> <li>• Atriopeptin in Atria and Plasma of Rats Orbited Aboard NASA Spacelab-3 for Seven Days (SL3 BSP3)</li> <li>• Results of Examination of the Respiratory System in Spacelab-3 Flight Rats (SL3 BSP30)</li> <li>• Hematologic Parameters of Astrorats Flown on Spacelab-3 (SL3 BSP26)</li> <li>• 1,25-Dihydroxyvitamin D3 Receptors in Space Flown vs. Grounded Control Rat Kidneys (SL3 BSP22)</li> <li>• Biochemical and Morphological Evaluation of the Effects of Space Flight on Rat Salivary Glands (SL3 BSP21)</li> <li>• Hepatic Enzymes of Sphingolipid and Glycerolipid Biosynthesis in Rats from Spacelab 3 (SL3 BSP23)</li> <li>• Effects of Weightlessness on Neurotransmitter Receptors in Selected Brain Areas (SL3 BSP18)</li> <li>• Changes in Functional Metabolism in the Rat Central Nervous System Following Spaceflight (SL3 BSP17)</li> <li>• Osteocalcin as an Indicator of Bone Metabolism During Spaceflight (SL3 BSP10)</li> <li>• Reduction of the Spermatogonial Population in Rat Testes Flown on Spacelab 3 (SL3 BSP20)</li> <li>• Microgravity Changes in Heart Structure and Cyclic-AMP Metabolism (SL3 BSP2)</li> <li>• Morphological and Biochemical Changes in Soleus and Extensor Digitorum Longus Muscles of Rats Orbited in Spacelab 3 (SL3 BSP13)</li> </ul>
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<p>STS-51B/ Spacelab 3</p>	<ul style="list-style-type: none"> <li>• Roberts, W. Eugene; Fielder, P. J.; Gonsalves, M. R. R.; Maese, A. C.; Rosenner, L. M. L.</li> <li>• Rosenberg, Gary D. D.; Simmons, David J. J.</li> <li>• Ross, Muriel D.; Chee, Oliver; Donovan, Kathleen.</li> <li>• Russell, Jean E.; Simmons, David J. J.</li> <li>• Schneider, Howard J.</li> <li>• Steffen, Joseph M.; Musacchia, X. J.</li> <li>• Tischler, Marc E.; Cook, Paul H.; Henriksen, Erik J.; Jacob, Stephen.</li> <li>• Wronski, Thomas J. J.; Maese, A. C.; Morey- Holton, Emily R.; Walsh, C.</li> </ul>	<ul style="list-style-type: none"> <li>• Census of Osteoblast Precursor Cells in Periodontal Ligament (PDL) of Spacelab-3 Rats (SL3 BSP16)</li> <li>• Electron Microprobe Analyses of Calcium, Sulfate, Magnesium, and Phosphorous Distribution in Incisors of Spacelab-3 Rats (SL3 BSP6)</li> <li>• Otoconial Morphology in Space-Flown Rats (SL3 BSP19)</li> <li>• Bone Maturation in Rats Flown on the Spacelab-3 Mission (SL3 BSP14)</li> <li>• Urine Monitoring System (UMS) Effect of Seven Days of Spaceflight on Hindlimb Muscle Protein, RNA and DNA in Adult Rats (SL3 BSP8)</li> <li>• Response of Amino Acids in Hindlimb Muscles to Recovery from Hypogravity and Unloading by Tail-Cast Suspension (SL3 BSP11)</li> <li>• Space Lab 3: Histomorphometric Analysis of the Rat Skeleton (SL3 BSP15)</li> </ul>
<p>STS-61A/ Spacelab D-1</p>	<ul style="list-style-type: none"> <li>• Baisch F.; Beck L.; Samel M.D.; Samel A.; Montgomery L.D.</li> <li>• Bouteille M.</li> <li>• Buecker H.; Facius R.; Horneck, G; Reitz, G.; Graul, E.H.; Berger H.; Hoeffken H.; Ruether w.; Heinrich W.; Beaujean R.; Enge W.</li> <li>• Buecker H.; Reitz G.; Facius R.; Beaujean R.; Enge W.; Heinrich W.; Ohrndorf T.; Schopper E.</li> <li>• Ciferri O.; Tiboni O.; Di Pasquale G.; Orlandoni A.M.; Marchesi M.L.</li> <li>• Cogoli A.; Bechler B.; Mueller O.; Hunzinger E.</li> <li>• Cogoli A.; Bechler B.; Mueller O.; Hunzinger E.</li> <li>• Draeger J.; Wirt R.; Schwartz R.</li> <li>• Friederici A.D.; Levelt W.J.M.</li> <li>• Kirsch K.L.; Roecker L.; Haenel, F.</li> <li>• Marco M.; Gonzales-Jurardo J.; Vernos I; Calleja M.; Carratala M.</li> <li>• Mennigmann H.D.; Lange M.</li> <li>• Mergenhagen D.; Mergenhagen E.</li> <li>• Mittelstaedt H.; Glasauer S.</li> <li>• Neubert J.; Briegleb W.; Schartz A; Herwig I.; Kruse B.</li> <li>• Perbal G.; Driss-Ecole D.; Salle G.; Raffin J.</li> <li>• Planel H.; Richoilley G.; Tixador R.; Templier J.; Bes J.C.; Gasset G.</li> <li>• Ross H.E.; Schwarz E.; Emmerson P.</li> <li>• Sobick V.; Block I.; Briegleb W.; Wohlfart-Botterman K.E.</li> <li>• Theimer, R.R.; Kudielka, R.A.; Rösch I; Koch H.</li> </ul>	<ul style="list-style-type: none"> <li>• Early adaptation to body fluid and cardiac performance</li> <li>• Effect of microgravity on hybridoma mammalian cell behaviour and structure</li> <li>• Embryogenesis and organogenesis of <i>Carausius morosus</i> under spaceflight conditions</li> <li>• Dosimetric mapping inside Biorack</li> <li>• Effects of microgravity on genetic recombination in <i>Escherichia coli</i></li> <li>• Effects of microgravity on lymphocyte activation (ex-vivo)</li> <li>• Effects of microgravity on lymphocyte activation (in-vitro)</li> <li>• Tonometry</li> <li>• Spatial description: aspects of cognitive adaptation</li> <li>• Venous pressure in space</li> <li>• Embryogenesis of <i>Drosophila melanogaster</i></li> <li>• Growth and differentiation of <i>Bacillus subtilis</i> under microgravity conditions</li> <li>• The circadian clock of <i>Chlamydomonas reinhardtii</i> in space</li> <li>• Causation of inversion illusions and space sickness</li> <li>• Structure and function of the gravireceptor.</li> <li>• Graviperception of lentil seedling roots grown in space</li> <li>• The Paramecium experiment</li> <li>• Mass discrimination and adaptation to weightlessness</li> <li>• Contraction behaviour and protoplasmic streaming in the slime mould</li> <li>• Differentiation and Embryogenesis in Aniseed Cell Cultures in Microgravity</li> </ul>

<p>STS-61A/ Spacelab D-1</p>	<ul style="list-style-type: none"> <li>• Tixador L.; Lapchine L.; Moatti N.; Richoilley G.; Templier J.; Gasset G.</li> <li>• Ubbels G.A.</li>   <li>• Veringa F.</li> <li>• Vermeer C.; Ulrich M.M.W.</li> <li>• Volkmann D.; Behrens H.M.; Sievers A.</li> <li>• von Baumgarten R.</li> <li>• Young, Laurence R.</li> </ul>	<ul style="list-style-type: none"> <li>• Antibacterial activity of antibiotics in space conditions</li>   <li>• The role of gravity in the establishment of the dorso-ventral axis in the amphibian embryo</li> <li>• Arm positioning</li> <li>• The effect of microgravity on plasma-osteocalcin</li> <li>• Gravireception of cress roots (<i>Lepidium sativum</i> L.)</li>   <li>• European experiments on the vestibular system</li> <li>• Vestibular Adaptation (284065)</li> </ul>
<p>STS-40/ Spacelab Life Sciences 1</p>	<ul style="list-style-type: none"> <li>• Alfrey, Clarence P.; Driscoll, Theda B.; Nachtman, R.G.; Udden, M. M.</li> <li>• Alfrey, Clarence P.; Leach- Huntoon, Carolyn S.; Udden, Mark M.</li> <li>• Arnaud, Claude D.; Cann, Christopher E.</li> <li>• Baldwin, Kenneth M.</li>   <li>• Bakulin, A. V.; Morey- Holton, Emily R.</li> <li>• Blomqvist, C.G.; Buckley, Jay C.; Gaffney, F.A.; Lane, L.D.; Levine, B.D.; Peshock, R.M.; Watenpaugh, D.E.; Wright, S.J.</li> <li>• Cogoli, A.; Bechler, B.; Cogoli-Greuter, M.; Criswell, S.B.</li> <li>• Cogoli, A.; Bechler, B.; Cogoli-Greuter, M.; Criswell, Sue B.; Hunzinger, E.; Joller, H.; Joller, P.; Dyachkova, L.N.; Lowry, O.H.</li> <li>• Eckberg, Dwain L.; Fritsch- Yelle, Janice M.</li> <li>• Farhi, Leon E.; Klocke, Robert A.; Olszowka, Albert J.; Pendergast, David R.; Rokitka, Mary Ann; Shykoff, B. E.</li> <li>• Gerzer, R.</li> <li>• Gerzer, R.</li>   <li>• Gharib, C.; Ballard, R.V.; Davet, J.; Gabrion, J.; Herbuté, S.; Olivier, J.; Viso, M.</li> <li>• Gharib, Claude; Gabrion, Jacqueline; Pequignot, Jean-Marc; Sonnenfeld, Gerald.</li> <li>• Gershtein, L. M.; D'Amelio, Fernando E.; Daunton, Nancy G.; Mehler, William R.; Sergutina, A. V.</li> <li>• Grindelnd, Richard E.</li>   <li>• Hoh, Joseph F.</li> </ul>	<ul style="list-style-type: none"> <li>• Regulation of Blood Volume During Spaceflight (178141 1/2)</li> <li>• The Influence of Space Flight on Erythrokinetics in Man (178261 1/2)</li> <li>• Pathophysiology of Mineral Loss During Space Flight (178305 1/2)</li> <li>• Effects of Zero-Gravity Exposure on Biochemical and Metabolic Properties of Skeletal Muscle (178127 1/3)</li> <li>• Bone Biomechanics (SLS1 BSP2)</li>   <li>• Cardiovascular Adaptation to Zero Gravity (178294 1/2)</li>   <li>• Lymphocyte proliferation in weightlessness</li>   <li>• Ultrastructure of the Brain Cortex (SLS1 BSP12)</li>   <li>• Influence of Weightlessness Upon Human Autonomic Cardiovascular Control (178022 1/2)</li> <li>• Inflight Study of Cardiovascular Deconditioning (178066 1/2)</li>   <li>• Atrial natriuretic peptide and guanylate cyclase</li> <li>• Determination of ANF Receptors and of Particulate Guanylate Cyclase from Rats Flown in Weightlessness (SLS1 BSP25)</li> <li>• ANP binding sites are increased in choroid plexus of SLS-1 rats after 9 days of space flight</li>   <li>• Catecholamines, Vasopressin, Atrial Natriuretic Factor (ANF) and ANF Receptors in the Rat Brain (SLS1 BSP19)</li> <li>• Cytochemistry of Neurons (SLS1 BSP13)</li>   <li>• Effects of Spaceflight on Anterior Pituitary Receptors (SLS1 BSP21)</li> <li>• Skeletal Myosin Isoenzymes in Rats Exposed to Zero-Gravity (178247)</li> </ul>

STS-40/  
Spacelab Life  
Sciences 1

- Kaplansky, A. S.; Alekseyev, E. I.; Burkovskaya, T. E.; Durnova, G. N.; Fedotova, N. Y.; Frontasyeva, M. V.; Gundorina, S. F.; Ilyina-Kakueva, E. I.; Loginov, V. I.; Morey- Holton, Emily R.; Nazarov, V. M.; Popova, Irena A.
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- Krasnov, Igor B.; Drobyshev, V. I.; Edgerton, V. Reginald; Lowry, Oliver H.; Polyakov, I. V.
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- Muller, Otfried.
- Natochin, Yuri V.; Ivanova, S. Y.; Keil, Lanny C.; Lavrova, E. A.; Serova, Luba V.; Shakhmatova, E. I.; Snetkova, E. V.
- Oganov, Victor S.; Kabitskaya, Olga E.; Morey- Holton, Emily R.; Sumarokov, D. D.
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- Paiva, M.; Elliott, A.R.; Guy, H.J.B.; Prisk, G.K.; West, J.B.
- Popova, Irena A.; Markin, A. A.; Merrill, Alfred H.; Zhuravleva, O. A.
- Riley, Danny A.; Ellis, Stanley; Haas, A. L.
- Ross, Muriel D.
- Smirnov, K. V.; Goncharova, N. P.; Pechyonkina, R. A.; Phillips, Robert W.
- Metabolic and Structural Changes in Bone and Systems Regulating Bone Growth and Metabolism (SLS1 BSP3)
- Effect of Spaceflight Factors on the Functional Activity of Immune Cells (SLS1 BSP9)
- Histochemistry of Hypothalamus (SLS1 BSP17)
- Spinal Cord and Dorsal Root Ganglion Morphology and Histochemistry (SLS1 BSP16)
- Primary Perceptive Structure of the Brain: Morphology and Histochemistry (SLS1 BSP10)
- Regulation of Erythropoiesis During Spaceflight (178012 1/2)
- Fluid-Electrolyte Regulation During Space Flight (178192 1/2)
- Morphology of Neurons of the Brain Cortex (SLS1 BSP18)
- Neuronal Morphology (SLS1 BSP11)
- Bone, Calcium, and Spaceflight (178194 1/2)
- Lymphocyte Proliferation in Weightlessness (178240 1/1)
- Tissue Fluid-Electrolyte Composition (SLS1 BSP15)
- Osteogenesis: Tissue Factors of Regulation (SLS1 BSP4)
- Contractile Properties of Skeletal Muscles (SLS1 BSP14)
- Ventilatory inhomogeneity determined from multiple-breath washouts during sustained microgravity on Spacelab SLS-1
- Lipid Peroxidation and Antioxidant Defense System (SLS1 BSP5)
- Electron Microscopy, Light Microscopy, and Protease Activity of Rat Hindlimb Muscles (178303 1/2)
- Effects of Space Travel on Mammalian Gravity Receptors (178238 1/2)
- Mechanism of Formation of the Gastric Hypersecretory Syndrome of the Stomach (SLS1 BSP6)

<p>STS-40/ Spacelab Life Sciences 1</p>	<ul style="list-style-type: none"> <li>• Smirnov, K. V.; Goncharova, N. P.; Pechyonkina, R. A.; Phillips, R. W.</li> <li>• Smirnov, K. V.; Goncharova, N. P.; Lacy, Paul; Pechyonkina, R. A.</li> <li>• Spangenberg, Dorothy B.</li>   <li>• Stein, T. Peter; Settle, R. Gregg.</li> <li>• West, John B.; Elliott, Ann; Guy, Harold; Prisk, G. Kim; Wagner, Peter D.</li> <li>• Szylit, O.; Andrieux, C.; Meslin, J.C.; Nugon-Baudon, L.; Rabot, S.; Viso, M.</li> <li>• Szylit, Odette; Andrieux, C.; Nugon-Baudon, I.; Ravisse, R.</li>   <li>• West, John B.; Elliott, Ann; Mathieu-Costello, O.</li> <li>• Young, Laurence R.; DeLuca, Carlo; Lichtenberg, Byron K.; Merfeld, Daniel; Money, Kenneth E.; Oman, Charles M.; Roy, Serge H.; Watt, Douglas G. D.</li> </ul>	<ul style="list-style-type: none"> <li>• Study of the Digestive Transportation Function of the Small Intestine (SLS1 BSP8)</li> <li>• Mechanisms of Changes in the Exocrine Functions of the Pancreas (SLS1 BSP7)</li> <li>• Effects of Microgravity-Induced Weightlessness on Aurelia Ephyra Differentiation and Statolith Synthesis(DCL(SLS-1))</li> <li>• Protein Metabolism During Space Flight (178120 1/2)</li> <li>• Pulmonary Function During Weightlessness (178198 1/2)</li>   <li>• Influence of microgravity on different metabolic potentials of intestinal microflora</li>   <li>• Effect of Microgravity on the Relations Between Microbiological and Epithelial Tissue and Functions of the Gastrointestinal Tract (SLS1 BSP20)</li> <li>• Histologic Examination of Lung Tissue (SLS1 BSP1)</li>   <li>• Vestibular Experiments in Spacelab (178072 1/2)</li> </ul>
<p>STS-42/ International Microgravity Laboratory 1</p>	<ul style="list-style-type: none"> <li>• Alexander, Harold L.</li> <li>• Block I.; Wolke A.; Briegleb W.</li>   <li>• Briarty L.G.; Maher E.P.; Iverse T.H.</li> <li>• Brown, Allan H.; Chapman, David K.; Heathcote, David G.; Johnsson, Anders.</li> <li>• Bruschi C.V.; Esposito M.S.</li> <li>• Buecker H.</li>   <li>• Cogoli A.; Bechler B.; Hunzinger E.; Mueller O.</li> <li>• Cogoli A.; Bechler B.</li>   <li>• Cogoli A.; Gmuender F.K.; Lorenzi G.; Nordau C.G.</li> <li>• Duke, Pauline Jackie</li>   <li>• Heathcote, David G.; Brown, Allan H.; Chapman, David K.</li> <li>• Marco R.; Gonzalez-Jurado J.; Calleja M.; Manzanares M.; Maroto M.; de Juan E.; Miquel J.</li> <li>• Mennigmann H.D.; Heise M.</li>   <li>• Nelson, Gregory A.</li>   <li>• Perbal G.; Driss-Ecole D.; Raffin J.</li>   <li>• Pross, H.D.</li> </ul>	<ul style="list-style-type: none"> <li>• Mental Workload and Performance Experiment (15-IML-1)</li> <li>• Gravity-related behaviour of the acellular slime mould Physarum polycephalum</li> <li>• Growth, differentiation and development of Arabidopsis thaliana under microgravity conditions</li> <li>• Gravitropic Threshold (GTHRES) (178236)</li>   <li>• Microgravitational effects on chromosome behaviour</li> <li>• Embryogenesis and organogenesis of carausius morosus under space flight conditions</li> <li>• Friend Leukemia virus transformed cells exposed to microgravity in the presence of dimethylsulfoxide</li> <li>• Proliferation and performance of hybridoma cells in microgravity</li> <li>• Cultivation of hamster kidney cells in a dynamic culture system in space</li> <li>• Chondrogenesis in Micromass Culture of Mouse Limbud Mesenchyme Exposed to Microgravity (284020)</li> <li>• Response to Light Stimulus Phototropic Transients (FOTRAN) (178054)</li> <li>• Effects of space environment on the development and of ageing of Drosophila melanogaster</li>   <li>• Growth and sporulation in Bacillus subtilis under microgravity</li> <li>• Genetic and Molecular Dosimetry of HZE Radiation (284050)</li> <li>• Transmission of gravistimulus in the statocyte of lentil roots grown in space</li> <li>• Repair of radiation induced genetic damage under microgravity</li> </ul>

<p>STS-42/ International Microgravity Laboratory 1</p>	<ul style="list-style-type: none"> <li>• Rasmussen O.; Baggerud C.; Iversen T.H.</li> <li>• Reitz G.; Facius R.; Beaujean R.; Heilmann C.</li> <li>• Reschke, Millard F.</li> <li>• Tixador R.; Gasset G.; Eche B.; Moatti N.; Lapchine L.; Woldringh C.; Toorop P.; Moatti J.P.; Delmotte F.; Tap G.</li> <li>• Ubbels G.A.; Reijnen M.; Meijerink J.; Narraway J.</li> <li>• Veldhuijzen J.P.; van Loon J.J.W.A.</li> </ul>	<ul style="list-style-type: none"> <li>• Effect of microgravity environment on cell wall regeneration, cell division, growth and differentiation of plant from protoplasts</li> <li>• Dosimetric mapping in Biorack</li> <li>• Microgravity Vestibular Investigations (284058)</li> <li>• Studies on penetration of antibiotic in bacterial cells in space conditions</li> <li>• The role of gravity in the establishment of the dorso-ventral axis in the Amphibian embryo</li> <li>• Effect of microgravity and mechanical stimulation on the in vitro mineralisation and resorption in fetal mouse long bones</li> </ul>
<p>STS-47/ Spacelab J</p>	<ul style="list-style-type: none"> <li>• Charles, John B.</li> <li>• Cowings, Patricia S.; Kamiya, Joe; Miller, Neal E.; Toscano, William B.</li> <li>• Ikenaga, Mitsuo.</li> <li>• Krikorian, Abraham D.</li> <li>• Koga, K.</li> <li>• LeBlanc, Adrian D.</li> <li>• Lloyd, Charles.</li> <li>• Miyoshi, Yasuhiro.</li> <li>• Mori, Shigeo.</li> <li>• Nagaoka, Shunji.</li> <li>• Partridge, N.; Sato, A.</li> <li>• Sato, Atsushige.</li> <li>• Sato, Atsushige.</li> <li>• Sekiguchi, Chiharu.</li> <li>• Seo, Hisao.</li> <li>• Souza, Kenneth A.; Black, Steven; Ross, Muriel D.; Wassersug, Richard.</li> <li>• Suda, T.</li> <li>• Tada, A.</li> </ul>	<ul style="list-style-type: none"> <li>• Lower Body Negative Pressure - Countermeasure Against Postflight Orthostatic Intolerance (178140)</li> <li>• Autogenic Feedback Training (178195 2/3)</li> <li>• Genetic Effects of HZE and Cosmic Radiation. (L-9)</li> <li>• Gravity and the Stability of the Differentiated State of Plant Embryos (8913036 1/2)</li> <li>• Comparative Measurement of Visual Stability in Earth and Cosmic Space. (L-4)</li> <li>• Magnetic Resonance Imaging (284029 1/3)</li> <li>• Fluid Therapy System (FTS 2/2)</li> <li>• A Circadian Rhythm of Condition in <i>Neurospora crassa</i>. (L-12)</li> <li>• Neurophysiological Study on Visuo-Vestibular Control of Posture and Movement of Fish during Adaptation to Weightlessness (L-2).</li> <li>• Study on Biological Effects of Cosmic Radiation and the Development of Radiation Protection Technology (L-11).</li> <li>• Bone Cell Growth and Mineralization in Microgravity (BCR)</li> <li>• Response of Plant Cells Under Microgravity.</li> <li>• The Effects of Microgravity on the Ultrastructure and Function of Cultured Mammalian Cells. (L-6)</li> <li>• Health Monitoring of Japanese Payload Specialist(L-0).</li> <li>• Endocrine and Metabolic Changes in Payload Specialist. (FMPT/L-1)</li> <li>• Effect of Weightlessness on Development of Amphibian Eggs (178256)</li> <li>• The Effects of Low Gravity on Calcium Metabolism and Bone Formation (FMPT/L-7)</li> <li>• Research on Perceptual-Motor Functions Under the Zero Gravity Condition (L-10).</li> </ul>
<p>STS-58/ Spacelab Life Sciences 2</p>	<ul style="list-style-type: none"> <li>• Alekseyev, E. I.</li> <li>• Alexandre, Christian; Bourrin, S.; Vico, Laurence.</li> <li>• Alfrey, Clarence P.</li> <li>• Alfrey, Clarence P.; Driscoll, Theda B.; Nachtman, Ronald G.; Udden, Mark M.</li> <li>• Arnaud, Claude D.</li> </ul>	<ul style="list-style-type: none"> <li>• Morphological Analysis of Pituitary Somatotrophs of SLS-1 and SLS-2 Rats (SLS2 BSP8)</li> <li>• Histomorphometric Analysis of Bone Tissue after Weightlessness Exposure and Recovery (SLS2 CNES8)</li> <li>• Influence of Space Flight on Erythrokinetics in Man (178261 2/2)</li> <li>• Regulation of Blood Volume During Spaceflight (178141 2/2)</li> <li>• Pathophysiology of Mineral Loss During Space Flight (178305 2/2)</li> </ul>

<p>STS-58/ Spacelab Life Sciences 2</p>	<ul style="list-style-type: none"> <li>• Baldwin, Kenneth M.; Ciozzo, Vince J.</li> <li>• Blomqvist, C. Gunnar</li>   <li>• Durnova, G. N.; Kaplansky, Alexander S.</li> <li>• Farhi, Leon E.</li>   <li>• Gabrion, Jacqueline; Bayard, Bernard; Bouille, Christian; Fagette, S.; Fareh, J.; Gauquelin, Guillemette; Gharib, Claude; Herbute, Serge; Oliver, Jacques.</li> <li>• Gabrion, Jacqueline; Bayard, Bernard; Bouille, Christian; Gharib, Claude; Herbute, Serge; Nguyen Than Dao, Brigitte; Oliver, Jacques.</li> <li>• Gabrion, Jacqueline; Cottet-Emard, J. M.; Fagette, S.; Fareh, J.; Gauquelin, Guillemette; Gharib, Claude; Pequignot, Jean-Marc.</li> <li>• Gharib, C.</li>   <li>• Ichiki, Albert T.; Allebban, Zuhair; Gibson, Linda A.</li> <li>• Ilyina-Kakueva, E. I.; Pozdnyakov, O. M.</li> <li>• Ivanova, S. M.; Popova, Irena A.</li>   <li>• Kaplansky, Alexander S.; Durnova, G. N.; Popova, Irena A.</li> <li>• Kato, Kanefusa; Naguma, Yataka.</li>   <li>• Konstantinova, Irina V.; Lesnyak, A. T.</li>   <li>• Konstantinova, Irina V.; Lesnyak, A. T.</li>   <li>• Konstantinova, Irina V.; Lesnyak, A. T.</li> <li>• Krasnov, Igor B.; Dyachkova, Ludmilla N.</li> <li>• Krasnov, Igor B.; Grindeland, Richard E.; Sawchenko, Paul E.; Vale, Wylie.</li> <li>• Krasnov, Igor B.; Grindeland, Richard E.; Sawchenko, P. E.; Vale, Wylie.</li>   <li>• Leach-Huntoon, Carolyn S.</li>   <li>• Loginov, V. I.</li>   <li>• Marini, Jean Francois; Leger, Jean J.; Zamora, Alfredo J.</li> </ul>	<ul style="list-style-type: none"> <li>• Effects of Zero-Gravity Exposure on Biochemical and Metabolic Properties of Skeletal Muscle (178127 3/3)</li> <li>• Cardiovascular Adaptation to Zero Gravity (178294 2/2)</li> <li>• Histomorphometric Study of SLS-2 Rat Tibia (SLS2 BSP27)</li> <li>• Inflight Study of Cardiovascular Deconditioning (178066 2/2)</li> <li>• ANP, Pro-ANP and mRNA Distribution in Rat Heart During a Space Flight (SLS2 CNES5)</li>   <li>• Ultrastructural Changes in Choroid Plexus of Rats Maintained in Microgravity During a Spaceflight (SLS2 CNES4)</li>   <li>• Central (brainstem) and Peripheral (heart and kidney) Sympathetic Activity During a Space Flight (SLS2 CNES6)</li>   <li>• Central and peripheral noradrenergic responses to 14 days of spaceflight or hindlimb suspension in rats</li> <li>• Regulation of Erythropoiesis During Spaceflight (178012 2/2)</li> <li>• Morphological Investigations of Skeletal Muscles of SLS-2 (SLS2 BSP3)</li> <li>• Cellular Homeostasis in Microgravity: Energy and Structure (SLS2 BSP33)</li> <li>• The Stressogenic Effect of Microgravity: Biochemical Studies (SLS2 BSP15)</li> <li>• Biochemistry of Muscle Fiber Specific Proteins Under Microgravity (SLS2 NASDA4)</li> <li>• Effect of SLS-2 Space Flight on Immunological Parameters of Rats: Immunity Mediators (SLS2 BSP11)</li> <li>• Effect of SLS-2 Space Flight on Immunological Parameters of Rats: Antiviral Immunity (SLS2 BSP12)</li> <li>• Effect of SLS-2 Space Flight on Immunological Parameters of Rats: Bone and Immunity (SLS2 BSP13)</li> <li>• Morphology of End and Intermediate Brain (SLS2 BSP1)</li> <li>• Morphology and Histochemistry of Proprioceptive Cerebellum (SLS2 BSP20)</li>   <li>• Ultrastructure and Histochemistry of Vestibular Structures and Vegetative Nuclei of the Brain (SLS2 BSP2)</li> <li>• Fluid-Electrolyte Regulation During Space Flight (178192 2/2)</li> <li>• Functional State of Thyroid and Calcitonin Producing System of Rat Thyroid Gland in Microgravity (SLS2 BSP7)</li> <li>• Morphological and Functional Adaptations of Muscle Fibers, and Muscle-Tendon and Nerve-Muscle Junctions to Spaceflights (SLS2 CNES2)</li> </ul>
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<p>STS-58/ Spacelab Life Sciences 2</p>	<ul style="list-style-type: none"> <li>• Mironneau, Chantal; Mironneau, J.; Neuilly, G.; Rakotoarisoa, L.; Sayet-Colombet, L.</li> <li>• Morey- Holton, Emily R.; Cann, Christopher E.; Doty, Stephen B.; Roberts, W. Eugene; Vailas, Arthur C.</li> <li>• Mounier, Yvonne; Cordonnier, Corinne; Stevens, Laurence.</li>   <li>• Oganov, Victor S.; Kabitskaya, Olga E.; Rodionova, N. V.</li> <li>• Ohira, Yoshinob; Saito, Kazuto.</li>   <li>• Paiva, M.</li>   <li>• Riley, Danny A.; Ellis, Stanley.</li> <li>• Ross, Muriel D.</li>   <li>• Serova, Luba V.; Natochin, Yuri V.</li>   <li>• Shigematsu, Taashi; Yamauchi, Hogara.</li> <li>• Stein, T. Peter</li> <li>• Szylit, Odette; Amdrieux, C.; Nugon- Baudon, L.</li>   <li>• West, John B.</li>   <li>• Yoshioka, Toshitada; Tomoyukiunishima, M. D.; Yamashita, Katsumas.</li> <li>• Young, Laurence R.</li> <li>• Zerath, Erik; Marie, Pierre J.</li> </ul>	<ul style="list-style-type: none"> <li>• Molecular Pharmacology of Alpha-1 Adrenoreceptors and Calcium Channels in Rat Vascular Myocytes (SLS2 CNES3)</li> <li>• Bone, Calcium, and Spaceflight (178194 2/2)</li>   <li>• Single Fiber Muscle Function (SLS2 CNES1)</li>   <li>• Bone Minerals and Morphological and Functional Changes (SLS2 BSP5)</li> <li>• Effects of Spaceflight on beta-Adrenoceptors in Rat Hindlimb Muscles (SLS2 NASDA2)</li> <li>• Anomalous behavior of helium and sulphur hexafluoride during single-breath tests in sustained microgravity.</li> <li>• Electron Microscopy, Light Microscopy, and Protease Activity of Rat Hindlimb Muscles (178303 2/2)</li> <li>• Effects of Space Travel on Mammalian Gravity Receptors (178238 2/2)</li> <li>• Kidneys and Fluid-Electrolyte Homeostasis (SLS2 BSP9)</li> <li>• Bone Metabolism Under the Condition without Gravity (SLS2 NASDA1)</li> <li>• Protein Metabolism During Space Flight (178120 2/2)</li> <li>• Influence of Microgravity on Rat Digestive Physiology and Xenobiotic Metabolizing System - Interactions with Intestinal Microflora Alterations (SLS2 CNES9)</li> <li>• Pulmonary Function During Weightlessness (178198 2/2)</li> <li>• Histochemical and Biochemical Studies on Slow, Fast, and Heart Muscle in Rats (SLS2 NASDA3)</li>   <li>• Vestibular Experiments in Spacelab (178072 2/2) Bone Cell Activity During Spaceflight and Recovery (SLS2 CNES7)</li> </ul>
<p>STS-55/ Spacelab D-2</p>	<ul style="list-style-type: none"> <li>• Arbeille, Ph.; Blomqvist, C.G.</li> <li>• Baisch F.J.; Beck L.E.J.; Blomqvist C.G.; Karemaker J.M.</li> <li>• Baisch F.J.; Beck L.E.J.; Karemaker J.M.; Pourcelot L.; Linnarsson D.; Tedner B.</li> <li>• Beck L.E.J.; Baisch F.J.; Karemaker J.M.; Arbeille Ph.; Pourcelot L.</li> <li>• Blomqvist, C. Gunnar.</li>   <li>• Buecker, H.; Reitz, G.</li>   <li>• Donhauser, D.</li> <li>• Draeger J.; Schwartz R.; Stern C.; Groenhoff S.; Hechler B.</li> <li>• Eckberg, Dwain L.; Brown, Troy E.; Convertino, Victor J.; Doerr, D. F.</li> <li>• Eisenbeiss, M.</li> </ul>	<ul style="list-style-type: none"> <li>• Cardiovascular regulation at 0 g</li> <li>• Leg fluid distribution at rest and under lower body negative pressure</li> <li>• Determination of segmental fluid content and perfusion</li>   <li>• Left ventricular configuration and function at rest and under stimulation</li> <li>• Cardiovascular Regulation at Microgravity (284080 1/2)</li> <li>• Performance of the personal dosimetry of the astronaut's ionizing radiation exposure</li> <li>• Yeast metabolism</li> <li>• Tonometry - intraocular pressure</li>   <li>• Influence of Microgravity upon the Carotid Baroreceptor-Cardiac Reflex Response (178022 2/2)</li> <li>• Electrofusion of protoplasts from Digitalis Lanata EHRH, and Digitalis Purpurea L. suspension cultures under microgravity conditions and enzymatic characterization of the fusion products</li> </ul>



<p>STS-55/ Spacelab D-2</p>	<ul style="list-style-type: none"> <li>• Fern E.B.; Ballèvre O.P.; Piguet-Welsch C.; Schierbeek H.; Acheson K.J.</li> <li>• Foldager N.; Andersen T.A.E.; Jessen F.B.; Ellegaard P.; Stadeager C.; Videbaek R.; Norsk P.</li> <li>• Gerzer R.; Drummer C.; Lang R.; Well J.; Stromeyer H.</li> <li>• Hampp, R.</li> <li>• Henriksen O.; Norsk P.; Boisen J.; Foldager N.; Jessen F.; Karemaker J.; Sadamoto S.; Sejrsen P.</li> <li>• Hock, B.</li> <li>• Horn, E.</li> <li>• Horneck, G.</li> <li>• Jung-Heiliger, H.</li> <li>• Kirsch K.A.; Baartz F.J.; Gunga H.-Chr.; Roecker L.</li> <li>• Linnarsson D.; Larsson H.</li> <li>• Maass, H.</li> <li>• Mennigmann, H.D.</li> <li>• Mennigmann, H.D.</li> <li>• Mueller, P.K.</li> <li>• Neubert, J.</li> <li>• Norsk P.; Bie P.; Christensen N.J.; Warberg J.; Stadeager C.</li> <li>• Obe, G.</li> <li>• Paiva, M.</li> <li>• Rahmann, H.</li> <li>• Reitz, G.</li> <li>• Reske, K.</li> <li>• Reske, K.</li> <li>• Riondino, G.; Scano, A.; Strollo F.; Strollo, G.</li> <li>• Roecker, L.; Kirsch, K.A.; Gunga, H. C.</li> <li>• Stegemann J.</li> <li>• Volkmann, D.</li> <li>• von Keller, A.</li> </ul>	<ul style="list-style-type: none"> <li>• Changes in the rate of whole body nitrogen turnover, protein synthesis and protein breakdown</li> <li>• Central venous pressure</li> <li>• Regulation of volume homeostasis in weightlessness: possible involvement of atrial natriuretic factor and cyclic GMP</li> <li>• Electrofusion of plant cell protoplasts: Synthesis and morphological/biochemical characterization of heterospecific hybrids</li> <li>• Peripheral and central hemodynamics</li> <li>• Fruiting body development</li> <li>• Development of vestibuloocular reflex</li> <li>• Biological response to extraterrestrial solar ultraviolet radiation and space vacuum</li> <li>• Significance of gravity and calcium ions on the production of secondary metabolites in cell suspensions of <i>Aesculus hippocastanum</i> L.</li> <li>• Tissue thickness and tissue compliance. A long body axis under micro-g conditions</li> <li>• Pulmonary perfusion and ventilation at rest and exercise</li> <li>• Effects of Microgravity on Glucose Tolerance</li> <li>• Fluctuation test of bacteria cultures</li> <li>• Influence of conditions in space on expression and stability of genetic information in bacteria.</li> <li>• Influence of gravity on proliferation and biosynthetic capacity of isolated mesenchymal cells</li> <li>• Graviperception and neuronal plasticity: comparative investigations of weightlessness effects on structural development and function of the gravity perceiving organ of two water living vertebrates (<i>Xenopus laevis</i>, <i>Oreochromis mossambicus</i>)</li> <li>• The influence of microgravity on endocrine and renal elements of volume homeostasis in man</li> <li>• Chromosome aberration</li> <li>• Ventilation Distribution in Microgravity</li> <li>• Graviperception and neuronal plasticity: structure and functional related neuronal plasticity of the central nervous system of aquatic vertebrates during early ontogenetic development under microgravity.</li> <li>• Radiation environment inside Spacelab</li> <li>• Antigen-specific activation of regulatory T-Lymphocytes to Lymphokine production</li> <li>• Growth of T-Lymphocytes</li> <li>• Effects of Spaceflight on Pituitary-Gonad-Adrenal Function in the Human</li> <li>• The Role of Volume Regulating Hormones and Plasma Proteins in Man for the Adaptation to Micro-G and for the Readaptation to Terrestrial Conditions</li> <li>• Effects of Microgravity on the Dynamics of Gas Exchange, Ventilation and Heart Rate in Submaximal Dynamic Exercise</li> <li>• Gravisensitivity of cress roots</li> <li>• Electrofusion and regeneration of sunflower protoplasts under microgravity considering the ultrastructure.</li> </ul>
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<p>STS-65/ International Microgravity Laboratory 2</p>	<ul style="list-style-type: none"> <li>• Block, I.; Briegleb, W., Wolke, A.</li> <li>• Bouloc, P.</li> <li>• Charles, John B.</li>   <li>• Cogoli, A.; Bechler, B.; Walther, I.</li>   <li>• Cogoli, A.; Cogoli-Greuter, M.; Meloni, M.A.; Pippia, A.; Sciola, L.; Spano, A.</li> <li>• Cogoli, A.; Cogoli-Greuter, M.; Meloni, M.A.; Pippia, A.; Sciola, L.; Spano, A.</li> <li>• Cogoli, A.; Cogoli-Greuter, M.; Morrison, D.R.</li> <li>• Haeder, D.P.</li> <li>• Hemmersbach, R.</li>   <li>• Horneck, G.; Baumstark-Khan, C.; Kozubek, S.; Rink, H.; Schaefer, M.; Schmitz, C.</li> <li>• Horneck, G.; Rettberg, P.</li> <li>• Iversen, T. H.</li>   <li>• Johnsson, A.</li> <li>• Krikorian, Abraham D.</li>   <li>• Marco, R.</li>   <li>• Marthy, H.-J.</li>   <li>• Perbal, G.</li> <li>• Pierson, Duane.</li> <li>• Reitz, G.</li> <li>• Schmitt, D.A.</li>   <li>• Sievers, A.</li> <li>• Spangenberg, Dorothy B.</li>   <li>• Ubbels, G.A.</li>   <li>• Volkmann, D.</li> <li>• Wiederhold, Michael L.</li> </ul>	<ul style="list-style-type: none"> <li>• Gravisensitivity and Gravigeotaxis of the slime mold <i>Physarum polycephalum</i>.</li> <li>• Cell microenvironment and membrane signal transduction in microgravity</li> <li>• Lower Body Negative Pressure: Countermeasure Investigation for Reducing Postflight Orthostatic Intolerance (DSO 623 (LBNP))</li> <li>• Effect of stirring and mixing in a bioreactor experiment in microgravity</li> <li>• Lymphocyte activation, differentiation, and adhesion-dependence of activation</li>   <li>• Lymphocyte movements and interactions</li>   <li>• Antigen presentation and T-cell proliferation in microgravity</li> <li>• Graviorientation in <i>Euglena gracilis</i></li> <li>• Influence of acceleration on the spatial orientation of <i>Loxodes</i></li> <li>• Radiation repair kinetics in bacteria and mammalian cells</li>   <li>• Efficiency of radiation repair in prokaryotes</li> <li>• Root orientation, growth regulation, adaptation, and agravitropic behaviour of genetically transformed root</li> <li>• Plant growth and random walk</li> <li>• Gravity and the Stability of the Differentiated State of Plant Embryos (8913036 2/2)</li> <li>• Investigation of the mechanisms involved in the effect of space microgravity on <i>Drosophila</i> development, behaviour and aging</li> <li>• The sea urchin larva, a potential model for studying biomineralization and demineralization process in space</li> <li>• Effect of microgravity on lentil morphogenesis</li> <li>• Microbial Air Sampler (IML2-49)</li> <li>• Dosimetric mapping inside Biorack</li> <li>• Effect of microgravity on cellular action: the role of cytokines</li> <li>• Gravidreaction of <i>Chara</i></li> <li>• Effects of Microgravity on <i>Aurelia Ephyra</i> Behavior and Development (8913069)</li> <li>• The role of gravity in the establishment of embryonic axes in the amphibian embryo</li> <li>• Gravisensitivity of Cress Roots</li> <li>• Early Development of a Gravity-Receptor Organ in Microgravity (8913083 1/3)</li> </ul>
<p>STS-71/ Spacelab Mir</p>	<ul style="list-style-type: none"> <li>• Bloomberg, Jacob J.; Reschke, M.; Paloski, W.; Kozlovskaya, I.; Kornilova L.; Barmin, V.; Sokolov, A.; Babayev, B.</li> <li>• Charles, John; Mikhaylov, Valeriy.</li>   <li>• Charles, John; Mikhaylov, Valeriy.</li>   <li>• Feedback, Daniel; Shenkman, Boris.</li>   <li>• Fortney, Suzanne; Mikhaylov, Valeriy.</li> </ul>	<ul style="list-style-type: none"> <li>• Eye-Head Coordination During Target Acquisition</li>   <li>• Physiological Response During Descent on the Space Shuttle</li> <li>• Studies of Orthostatic Tolerance With the Use of Lower Body Negative Pressure</li> <li>• Morphological, Histochemical and Ultrastructural Characteristics of Skeletal Muscle</li> <li>• Evaluation of Thermoregulation During Spaceflight</li> </ul>

STS-71/  
Spacelab Mir

- Jahns, Gary; Guryeva, T. S.; Dadasheva, Olga. Anderson, Page A.W.
- Conrad, Gary W.
- Doty, Stephen.
- Fermin, Cesar D.
- Fritsch, Bernd.
- Hester, P.Y.
- Lelkes, Peter I. Shimizu, T.
- Wentworth, Bernard C.
- James, John; Sauer, Richard L.; Mukhamedieva, Lana; Sinyak, Yuri.
- Lane, Helen; Grigoriev, Anatoly.
- Lane, Helen; Ivanova, Svetlana.
- Lane, Helen; Ivanova, Svetlana.
- Lane, Helen; Ogonov, Victor; Popova, Irina.
- Lane, Helen; Popova, Irina.
- Pierson, Duane; Konstantinova, Inessa.
- Putcha, Lakshmi; Goncharov, I.
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Alfrey, C. P.	STS-40/SPACELAB LIFE SCIENCES 1
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Jones, Dean P.	STS-51B/SPACELAB 3
Jones, J. B.	STS-51B/SPACELAB 3 STS-40/SPACELAB LIFE SCIENCES 1
Kabitskaya, O. E.	STS-40/SPACELAB LIFE SCIENCES 1 (2 exps.) STS-58/SPACELAB LIFE SCIENCES 2
Kalb, R.	STS-90/NEUROLAB
Kamiya, Joe	STS-47/SPACELAB J STS-51B/SPACELAB 3
Kamper, G. A.	STS-90/NEUROLAB

Kaneko, M.	STS-90/NEUROLAB
Karemaker, J. M.	STS-55/SPACELAB D-2 (4 exps.)
Katahira, K.	STS-90/NEUROLAB
Katsuta, S.	STS-90/NEUROLAB
Kato, Katharine H.	STS-51B/SPACELAB 3
Kayser, B.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Keil, L. C.	STS-51B/SPACELAB 3 STS-40/SPACELAB LIFE SCIENCES 1
Keremaker, J. M.	STS-90/NEUROLAB
Kharitonov, N. M.	STS-71/SPACELAB MIR
Kirsch, K. A.	STS-55/SPACELAB D-2
Klocke, Robert A.	STS-40/SPACELAB LIFE SCIENCES 1
Knierim, J. J.	STS-90/NEUROLAB
Koch, H.	STS-61A/SPACELAB D-1
Koizuka, I.	STS-90/NEUROLAB
Konstantinova, I.	STS-71/SPACELAB MIR (4 exps.)
Kornilova, L.	STS-71/SPACELAB MIR
Koryak, Y.	STS-71/SPACELAB MIR (5 exps.)
Kotov, A.	STS-71/SPACELAB MIR
Kozlovskaya, I.	STS-71/SPACELAB MIR
Kozubek, S.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2
Kraft, L. M.	STS-51B/SPACELAB 3
Kreavoy, A.	STS-71/SPACELAB MIR
Krikorian, Abraham D.	STS-3/OSS-1
Kronaurer, R. E.	STS-90/NEUROLAB
Kruse, B.	STS-61A/SPACELAB D-1
Kubo, T.	STS-90/NEUROLAB
Kudielka, R. A.	STS-61A/SPACELAB D-1
Lacquant, F.	STS-90/NEUROLAB
Lacy, Paul	STS-40/SPACELAB LIFE SCIENCES 1
Lane, H.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Lane, L. D.	STS-40/SPACELAB LIFE SCIENCES 1 STS-90/NEUROLAB
Lang, R.	STS-55/SPACELAB D-2
Lange, M.	STS-61A/SPACELAB D-1
Lange, R. D.	STS-40/SPACELAB LIFE SCIENCES 1
Lapchine, L.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1 STS-61A/SPACELAB D-1
Larsson, H.	STS-55/SPACELAB D-2
Lavrova, E. A.	STS-40/SPACELAB LIFE SCIENCES 1
Layne, C. S.	STS-71/SPACELAB MIR
Leach-Huntoon, Carolyn S.	STS-40/SPACELAB LIFE SCIENCES 1
Leger, J. J.	STS-58/SPACELAB LIFE SCIENCES 2
Lemay, R.	STS-3/OSS-1 STS-51F/Spacelab 2
Lencki, Walter A.	STS-51B/SPACELAB 3
Leon, H. A.	STS-40/SPACELAB LIFE SCIENCES 1
Leonard, J. I.	STS-40/SPACELAB LIFE SCIENCES 1
Lesnyak, A. T.	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2 (3 exps.)
Levelt, W. J. M.	STS-61A/SPACELAB D-1
Levine, B. D.	STS-40/SPACELAB LIFE SCIENCES 1 STS-90/NEUROLAB
Levinskikh, M. A.	STS-71/SPACELAB MIR
Lewis, E. R.	STS-90/NEUROLAB

Lichtenberg, B. K.	STS-40/SPACELAB LIFE SCIENCES 1
Lin, C. Y.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Linnarsson, D.	STS-55/SPACELAB D-2
Loginov, V. I.	STS-40/SPACELAB LIFE SCIENCES 1
Lorenzi, G.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Lowry, O. H.	STS-40/SPACELAB LIFE SCIENCES 1 (4 exps.)
Lundgren, P. R.	STS-51B/SPACELAB 3
Lyte, Mark	STS-51B/SPACELAB 3
Maese A. C.	STS-51B/SPACELAB 3 (2 experiments)
Maher, E. P.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Makhanov, M. A.	STS-40/SPACELAB LIFE SCIENCES 1 (2 exps.)
Mandel, A. D.	STS-51B/SPACELAB 3
Mano, T.	STS-90/NEUROLAB
Manzanares, M.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Marchesi, M. L.	STS-61A/SPACELAB D-1
Marie, P. J.	STS-58/SPACELAB LIFE SCIENCES 2
Marini, J. F.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Marion, Samuel L.	STS-51B/SPACELAB 3
Markin, A. A.	STS-40/SPACELAB LIFE SCIENCES 1 (2 exps.)
Maroto, M.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Martin, R. Bruce	STS-51B/SPACELAB 3
Martin, Thomas P.	STS-51B/SPACELAB 3
Martinelli, G. D.	STS-90/NEUROLAB
Mathieu-Costello, O.	STS-40/SPACELAB LIFE SCIENCES 1
Matsumoto, S.	STS-90/NEUROLAB
McCarthy, J.	STS-71/SPACELAB MIR
McConnaughey, Mona	STS-51B/SPACELAB 3
McIntyre, J.	STS-90/NEUROLAB
McMillen, B. A.	STS-51B/SPACELAB 3
Mednieks, Maija I.	STS-51B/SPACELAB 3
Meijerink, J.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Mehler, W. R.	STS-40/SPACELAB LIFE SCIENCES 1
Milesi, S.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Meloni, M. A.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2 (2 exps.)
Merfeld, D.	STS-40/SPACELAB LIFE SCIENCES 1
Mergenhagen, E.	STS-61A/SPACELAB D-1
Merrill, A. H.	STS-40/SPACELAB LIFE SCIENCES 1
Meshkov, D. O.	STS-40/SPACELAB LIFE SCIENCES 1
Meslin, J. C.	STS-40/SPACELAB LIFE SCIENCES 1
Miguel, J.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Miller, J. D.	STS-51B/SPACELAB 3
Miller, Neal E.	STS-47/SPACELAB J STS-51B/SPACELAB 3
Mikhaylov, V.	STS-71/SPACELAB MIR (6 exps.)
Mironneau, J.	STS-58/SPACELAB LIFE SCIENCES 2
Miyake, M.	STS-90/NEUROLAB
Miyamoto, Y.	STS-90/NEUROLAB
Moatti, J. P.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Moatti, N.	STS-61A/SPACELAB D-1
Moller, K.	STS-90/NEUROLAB
Money, K. E.	STS-40/SPACELAB LIFE SCIENCES 1
Montgomery, L. D.	STS-61A/SPACELAB D-1
Montufar-Solis, D.	STS-51B/SPACELAB 3
Moore, S.	STS-90/NEUROLAB

Morey-Holton, Emily R.	STS-51B/SPACELAB 3 STS-40/SPACELAB LIFE SCIENCES 1 (3 exps.)
Morrison, D. R.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2
Morrow, Jennifer	STS-51B/SPACELAB 3
Mottai, N.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Motter, K.	STS-51B/SPACELAB 3
Mueller, O.	STS-61A/SPACELAB D-1 (2 experiments) STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Mukhamedieva, L.	STS-71/SPACELAB MIR
Murakami, D. M.	STS-51B/SPACELAB 3 STS-90/NEUROLAB
Murasko, L. M.	STS-40/SPACELAB LIFE SCIENCES 1
Musaccia, X. J.	STS-51B/SPACELAB 3
Nachtman, R. G.	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2
Nagayama, T.	STS-90/NEUROLAB
Narraway, J.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Naguma, Yataka	STS-58/SPACELAB LIFE SCIENCES 2
Natochin, Y. V.	STS-58/SPACELAB LIFE SCIENCES 2
Nazarov, V. M.	STS-40/SPACELAB LIFE SCIENCES 1
Neri, D. F.	STS-90/NEUROLAB
Neubert, J.	STS-90/NEUROLAB
Neuilly, G.	STS-58/SPACELAB LIFE SCIENCES 2
Nguyen Than Dao, B.	STS-58/SPACELAB LIFE SCIENCES 2
Nordau, C. G.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Norsk, P.	STS-55/SPACELAB D-2 (2 exps.)
Nunes, C.	STS-73, USML 2
Nugon-Baudon, L.	STS-40/SPACELAB LIFE SCIENCES 1 (2 exps.) STS-58/SPACELAB LIFE SCIENCES 2
O'Connor, S. A.	STS-3/OSS-1
Ohkohchi, T.	STS-90/NEUROLAB
Ohrndorf, T.	STS-61A/SPACELAB D-1
Oishi, H.	STS-90/NEUROLAB
Olivier, J.	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2 (2 exps.)
Olszowka, Albert J.	STS-40/SPACELAB LIFE SCIENCES 1
Oman, C. M.	STS-40/SPACELAB LIFE SCIENCES 1 STS-78/LIFE AND MICROGRAVITY SPACELAB
Organov, V.	STS-71/SPACELAB MIR
Orlandoni, A. M.	STS-61A/SPACELAB D-1
Orlova, T. G.	STS-40/SPACELAB LIFE SCIENCES 1
Paiva, M.	STS-78/LIFE AND MICROGRAVITY SPACELAB STS-90/NEUROLAB
Paloski, W. H.	STS-78/LIFE AND MICROGRAVITY SPACELAB STS-71/SPACELAB MIR (4 exps.)
Papova, I.	STS-71/SPACELAB MIR (2 exps.)
Parker, D. E.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Parnas, B. R.	STS-90/NEUROLAB
Patil, L.	STS-51B/SPACELAB 3
Patterson, Buckendahl, Patricia	STS-51B/SPACELAB 3
Pawelczyk, J. A.	STS-90/NEUROLAB
Pechyonkina, R. A.	STS-40/SPACELAB LIFE SCIENCES 1 (3 exps.)
Pendergrast, David R.	STS-40/SPACELAB LIFE SCIENCES 1
Pequignot, Jean-Marc	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2

Peshock, R. M.	STS-40/SPACELAB LIFE SCIENCES 1
Peterson, C.	STS-3/OSS-1
Phillips, R. W.	STS-40/SPACELAB LIFE SCIENCES 1 (2 exps.)
Piguet-Welsch, C.	STS-55/SPACELAB D-2
Pike, J. Wesley	STS-51B/SPACELAB 3
Pippia, A.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2 (2 exps.)
Polyakov, I. V.	STS-40/SPACELAB LIFE SCIENCES 1
Pompeiano, M.	STS-90/NEUROLAB
Popova, I. A.	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2 (2 exps.)
Pos, G.	STS-90/NEUROLAB
Pourcelot, L.	STS-55/SPACELAB D-2 (2 exps.)
Pozdnyakov, O. M.	STS-58/SPACELAB LIFE SCIENCES 2
Prisk, G. K.	STS-40/SPACELAB LIFE SCIENCES 1 (2 exps.) STS-78/LIFE AND MICROGRAVITY SPACELAB STS-90/NEUROLAB
Rabot, S.	STS-40/SPACELAB LIFE SCIENCES 1
Raffin, J.	STS-61A/SPACELAB D-1 STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Rakotoarisoa, L.	STS-58/SPACELAB LIFE SCIENCES 2
Rambaut, P. C.	STS-40/SPACELAB LIFE SCIENCES 1
Ravisse, R.	STS-40/SPACELAB LIFE SCIENCES 1
Reijnen, M.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Reilly, T.	STS-51B/SPACELAB 3
Reitz, G.	STS-61A/SPACELAB D-1 (2 experiments) STS-55/SPACELAB D-2
Rephen, T.	STS-90/NEUROLAB
Reschke, M.	STS-71/SPACELAB MIR (4 exps.)
Rettberg, P.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2
Richoilley, G.	STS-61A/SPACELAB D-1 (2 experiments)
Riley, Danny A.	STS-40/SPACELAB LIFE SCIENCES 1
Rink, H.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2
Rispoli, E.	STS-9/SPACELAB 1
Roberts, W. E.	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2
Robertson, R. M.	STS-90/NEUROLAB
Rodionova, N. V.	STS-58/SPACELAB LIFE SCIENCES 2
Roecker, L.	STS-61A/SPACELAB D-1 STS-55/SPACELAB D-2
Rokitka, Mary Ann	STS-40/SPACELAB LIFE SCIENCES 1
Rosch, I.	STS-61A/SPACELAB D-1
Rosenner, L. M. L.	STS-51B/SPACELAB 3
Ross, Muriel D.	STS-47/SPACELAB J
Roy, R.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Roy, S. H.	STS-40/SPACELAB LIFE SCIENCES 1
Ruder, M.	STS-51B/SPACELAB 3
Ruether, W.	STS-61A/SPACELAB D-1
Rykova, M.P.	STS-40/SPACELAB LIFE SCIENCES 1
Sadamoto, S.	STS-55/SPACELAB D-2
Saito, Kazuto	STS-58/SPACELAB LIFE SCIENCES 2
Salle, G.	STS-61A/SPACELAB D-1
Sams, C.	STS-71/SPACELAB MIR
Samel, A.	STS-61A/SPACELAB D-1
Samel, M. D.	STS-61A/SPACELAB D-1

Sans, N.	STS-90/NEUROLAB
Sapp, Walter	STS-51B/SPACELAB 3
Sato, A.	STS-47/SPACELAB J
Satyanarayana, T.	STS-51B/SPACELAB 3
Sauer, R. L.	STS-71/SPACELAB MIR
Sawchenko, P. E.	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2 (2 expts.)
Sayet-Colombet, L.	STS-58/SPACELAB LIFE SCIENCES 2
Scano, A.	STS-55/SPACELAB D-2
Scarfone, E.	STS-90/NEUROLAB
Schaefer, M.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2
Schartz, A.	STS-61A/SPACELAB D-1
Schatte, Christopher	STS-51B/SPACELAB 3
Scheld, H. W.	STS-3/OSS-1 (2 experiments)
Schierbeck, H.	STS-55/SPACELAB D-2
Schlegel, R.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Schmitx, C.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2
Schopper, E.	STS-61A/SPACELAB D-1
Schwartz, R.	STS-61A/SPACELAB D-1 STS-55/SPACELAB D-2
Schwarz, E.	STS-61A/SPACELAB D-1
Scibetta, S.	STS-51B/SPACELAB 3
Sciola, L.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2 (2 expts.)
Scionolfi, S.	STS-71/SPACELAB MIR
Sedlack, F. R.	STS-51B/SPACELAB 3
Sejrsen, P.	STS-55/SPACELAB D-2
Sergutina, A. V.	STS-40/SPACELAB LIFE SCIENCES 1
Sergy, A.	STS-71/SPACELAB MIR
Serova, L. V.	STS-40/SPACELAB LIFE SCIENCES 1
Settle, R. G.	STS-40/SPACELAB LIFE SCIENCES 1
Shackelford, L.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Shakhmatova, E. I.	STS-40/SPACELAB LIFE SCIENCES 1
Shanahan, T. L.	STS-90/NEUROLAB
Sharp, Joseph C.	STS-51B/SPACELAB 3
Shenkman, B.	STS-71/SPACELAB MIR
Shykoff, B. E.	STS-40/SPACELAB LIFE SCIENCES 1
Simmons, David J. J.	STS-51B/SPACELAB 3 (2 experiments)
Sinyak, Y.	STS-71/SPACELAB MIR
Slocum, G. R.	STS-51B/SPACELAB 3
Šnetkova, E. V.	STS-40/SPACELAB LIFE SCIENCES 1
Sokolov, A.	STS-71/SPACELAB MIR
Sonnenfeld, G.	STS-51B/SPACELAB 3 (2 experiments) STS-40/SPACELAB LIFE SCIENCES 1
Spano, A.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2 (2 expts.)
Spooner, B.	STS-73, USML 2 (2 expts.)
Stadeager, C.	STS-55/SPACELAB D-2 (2 expts.)
Stevens, L.	STS-58/SPACELAB LIFE SCIENCES 2
Stevenson, James H.	STS-51B/SPACELAB 3
Steward, O.	STS-90/NEUROLAB
Strollo, F.	STS-9/SPACELAB 1 STS-55/SPACELAB D-2
Strollo, G.	STS-55/SPACELAB D-2
Stromeyer, H.	STS-55/SPACELAB D-2

Stussi, E.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Suki, W. N.	STS-40/SPACELAB LIFE SCIENCES 1
Sumarokov, D. D.	STS-40/SPACELAB LIFE SCIENCES 1
Takeda, S.	STS-90/NEUROLAB
Tap, G.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Tchekirda, I.	STS-71/SPACELAB MIR (4 exps.)
Tedner, B.	STS-55/SPACELAB D-2
Templier, J.	STS-61A/SPACELAB D-1 (2 experiments)
Tibbitts, T. W.	STS-73, USML 2
Tiboni, O.	STS-61A/SPACELAB D-1
Tischler, Marc E.	STS-51B/SPACELAB 3
Tixador, R.	STS-61A/SPACELAB D-1
Tomoyukiunishima, M. D.	STS-58/SPACELAB LIFE SCIENCES 2
Tononi, G.	STS-90/NEUROLAB
Toorop, P.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Toscano, William B.	STS-47/SPACELAB J STS-51B/SPACELAB 3
Tremor, J. W.	STS-51B/SPACELAB 3
Udden, Mark M.	STS-40/SPACELAB LIFE SCIENCES 1 (2 experiments) STS-58/SPACELAB LIFE SCIENCES 2
Uinas, R.	STS-90/NEUROLAB
Usui, S.	STS-90/NEUROLAB
Vailas, A. C.	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2
Vale, Wylie	STS-40/SPACELAB LIFE SCIENCES 1 STS-58/SPACELAB LIFE SCIENCES 2 (2 exps.)
van Loon, J.J. W.A.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Vasques, Marilyn	STS-51B/SPACELAB 3
Vernos, I.	STS-61A/SPACELAB D-1
Vico, L.	STS-58/SPACELAB LIFE SCIENCES 2
Videbaek, R.	STS-55/SPACELAB D-2
Viso, M.	STS-40/SPACELAB LIFE SCIENCES 1 (2 exps.)
Voronov, A.	STS-71/SPACELAB MIR (4 exps.)
Wagner, P. D.	STS-40/SPACELAB LIFE SCIENCES 1
Wago, H.	STS-90/NEUROLAB
Walsh, C.	STS-51B/SPACELAB 3
Walther, I.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2
Waki, H.	STS-90/NEUROLAB
Wang, Elaine	STS-51B/SPACELAB 3
Warberg, J.	STS-55/SPACELAB D-2
Wassersug, R.	STS-47/SPACELAB J
Watenpaugh, D. E.	STS-40/SPACELAB LIFE SCIENCES 1
Watt, D. G. D.	STS-40/SPACELAB LIFE SCIENCES 1
Well, J.	STS-55/SPACELAB D-2
West, J. B.	STS-40/SPACELAB LIFE SCIENCES 1
West, M.S.	STS-78/LIFE AND MICROGRAVITY SPACELAB
Wesseling, K. H.	STS-90/NEUROLAB
Whitson, P. A.	STS-71/SPACELAB MIR
Williams, C.S.	STS-51B/SPACELAB 3
Williams, H. L.	STS-51B/SPACELAB 3
Williams, Jo Ann	STS-51B/SPACELAB 3 (2 experiments)
Wirt, R.	STS-61A/SPACELAB D-1
Woldringh, C.	STS-42/INTERNATIONAL MICROGRAVITY LAB 1
Wohlfart-Botterman, K. E.	STS-61A/SPACELAB D-1
Wolke, A.	STS-65/INTERNATIONAL MICROGRAVITYLAB 2



Wong-Riley, M. T.	STS-90/NEUROLAB
Wright, Paul	STS-51B/SPACELAB 3
Wright, S. J.	STS-40/SPACELAB LIFE SCIENCES 1
Wyatt, J. K.	STS-90/NEUROLAB
Yamasaki, M.	STS-90/NEUROLAB
Yamashita, Katsumas	STS-58/SPACELAB LIFE SCIENCES 2
Yamauchi, Hogara	STS-58/SPACELAB LIFE SCIENCES 2
Yelle, J.	STS-71/SPACELAB MIR
Yoshida, K.	STS-90/NEUROLAB
Zamora, A. J.	STS-58/SPACELAB LIFE SCIENCES 2
Zhuravleva, O. A.	STS-40/SPACELAB LIFE SCIENCES 1
Zukin, R. S.	STS-90/NEUROLAB



**Appendix B:  
Hardware and Facilities**

Mission	Experiment Facilities and Hardware
STS-2/OSTA-1	Plant Growth Unit (PGU)
STS-3/OSS-1	Plant Growth Unit (PGU)
STS-9/ Spacelab 1	Ballistocardiograph Cell Culture Flasks Cellulose Nitrate-Daicel (CND) Chest Fastening Harness Exposure Tray Incubator Mass Discrimination Apparatus Passive Radiation Detectors Plant Growth Unit (PGU) Strain Gauge Connected to Needle and Tape Recorder Syringes Three-Axial Accelerometer Vestibular Helmet
STS-51F/ Spacelab 2	Plant Growth Unit (PGU)
STS-51B/ Spacelab 3	ARC Life Sciences Spacelab 3 Payload Composition Autogenic Feedback Training Experiment (AFTE) System Biotelemetry System (BTS): Implants and Antenna System, Receivers/Demodulators Dynamic Environment Measuring System (DEMS) Life Sciences Laboratory Equipment (LSLE) Microcomputer Research Animal Holding Facility (RAHF)
STS-61A/ Spacelab D-1	Applanation tonometer Biorack: BOTEX Body Impedance Measurement Device Camera and goggle apparatus Catheter with sensing tip Human Centrifuge Padded Board Space sled Vestibular helmet Visual stimuli
STS-40/ Spacelab Life Sciences 1	Accelerometer Recording Unit (ARU) Acetylene Rebreathing Cardiac Output System Analog Data Recorder (RACAL) Animal Enclosure Module (AEM) Ankle Torque Device Awareness of Position Setup Bag-in-Box (BIB) Assembly Bag Dryer Assembly Baroreflex Measurement System Bicycle Ergometer Biomedical Instrumentation Port (BIP) - Launch, Reentry Blood Holding Kit (Freezer) Blood Holding Kit (Refrigerator) Blood Pressure Monitor- Continuous, Intermittent Body Mass Measurement Device (BMMD) Body Restraint System (BRS) Bungee Harness Camcorder Cardiopulmonary Control Unit (CCU) Cardiopulmonary Rebreathing Unit (CRU) Cardiovascular / Cardiopulmonary Interface Panel (CV/CP) Cassette Data Tape Recorder (CDTR) Contact Lens Kit ECDS / Microcomputer System (EMS)

<p>STS-40/ Spacelab Life Sciences 1</p>	<p>EMG Amplifier  EMG Amplifier - Posture  EOG Amplifier  Echocardiograph  Electronics Control Assembly (ECA)  Gas Analyzer/Mass Spectrometer (GAMS)  Gas Tank Assembly (GTA)  General Purpose Transfer Unit (GPTU)  General Purpose Work Station (GPWS)  Goggles  Heart Rate Monitor  Hematocrit Minicentrifuge  Inflight Blood Collection System (IBCS)  Infusion Pump  Jellyfish Kit  Life Sciences Laboratory Equipment (LSLE) Microcomputer  Lower Body Negative Pressure Device (LBNP)  Low-Gravity Centrifuge  Mercury-in-Silastic "Whitney" Strain Gauge  Minioscilloscope  Olympus 802 Camcorder  Ocular Torsion Chair  Orbiter Refrigerator/Freezer  Otolith Spinal Reflex / "Drop" Station  Peripheral Venous Pressure Device  Physiological Monitoring System (PMS)  Pocket Voice Recorder  Rack Mounted Centrifuge  Rails - Narrow and Wide  Rebreathing Assembly (RBA)  Refrigerator/Incubator Module (R/IM)  Research Animal Holding Facility (RAHF)  Rod and Frame Apparatus  Rotating Dome  Saliva Collection Kit  Single Pass Auxiliary Fan (SPAF)  Spacelab Refrigerator/Freezer  Spirometry Assembly  Stocking Plethysmograph  Strip Chart Recorder  System for Measurement of Central Venous Pressure (SMCVP)  System for Venous Occlusion Plethysmography (SVOP)  Temperature Recorder  Tilt Frame  Tissue Culture Incubator  Tracer Kit  Urine Monitoring System (UMS)  US Lab Sled  Vacuum Interface Assembly (VIA)  Venous Occlusion Cuff Controller (VOCC)  Venous Occlusion Plethysmography - Cuff Gauge</p>
<p>STS-42/ International Microgravity Laboratory 1</p>	<p>Biorack: Lexan Tubes/Solid Agar Sandwiches, Radiation Cartridge Belt, Cell Chambers and Assemblies, Syringe Racks  Gravitational Plant Physiology Facility (GPPF): Middeck Ambient Stowage Insert (MASI), Plant Carry On Container (PCOC) #88 and 89.  Temperature Recorder</p>

STS-47/ Spacelab J	Autogenic Feedback Training Experiment (AFTE) System Dissecting Microscope Frog Embryology Unit (FEU) (Adult Frog Box/Egg Chambers/Kits) General Purpose Transfer Unit (GPTU) General Purpose Work Station (GPWS) Microscope Lighting System NASDA Cell Culture Chamber Refrigerator/Incubator Module (R/IM) Temperature Recorder
STS-58/ Spacelab Life Sciences 2	Bicycle Ergometer Gas Cylinder Assembly (GCA) General Purpose Transfer Unit (GPTU) General Purpose Work Station (GPWS) Inflight Blood Collection System (IBCS) Inflight Refill Unit (IRU) Olympus 802 Camcorder Research Animal Holding Facility (RAHF) Single Pass Auxiliary Fan (SPAF) Small Mass Measuring Instrument (SMMI) Spacelab Refrigerator/Freezer Tracer Kit
STS-55/ Spacelab D-2	Anthrorack Baroreflex Measurement System Biorack/Biolabor: BOTEX Exposure trays Filters Radiation dosimeters Self-tonometer "TOMEX" Urine Monitoring System (UMS)
STS-65/ International Microgravity Laboratory 2	Aquatic Animal Experiment Unit (AAEU) NASDA Life Science Cell Culture Kit (CCK) Refrigerator/Incubator Module (R/IM) Slow Rotating Centrifuge Microscope: Niedergeschwindigkeits Zentrifugen-Mikroskop (NIZEMI) Temperature Recorder
STS-71/ Spacelab Mir	Accelerometer Bicycle Ergometer Blood pressure/heart rate monitors Dietary Logbook Electromyogram electrodes Formaldehyde badges Grab Air Sampler Impaction Air Sampler Inflight Blood Collection System (IBCS) Lower Body Negative Pressure (LBNP) device Platform with foam rubber Safety harness Saliva Sampler Kit Skin temperature sensors Solid Sorbent Air Sampler (SSAS) Surface Sampler Kit (SSK) Treadmill Video Camera Visual targets Water Microbiology Kit

STS-73/United States Microgravity Laboratory 2	Astroculture Facility Commercial Generic Bioprocessing Apparatus: Fluid Processing Apparatus Spectrophotometer
STS-78/ Life and Microgravity Spacelab	Actillum Bag Dryer Assembly Bag-in-Box (BIB) Assembly Bar Code Reader (BCR) Binocular Optokinetic Stimulus Goggles (OKS) Blood Collection Belt (BCB) Calibration Syringe Dual Energy X-ray Absorptiometry (DEXA) Electrode Impedance Meter (EIM) Electromyograph (EMG) Electronic Light Occlusion Goggles (ELOG) Electronics Control Assembly (ECA) Ergometer III Exercise Breathing Assembly (EBA) Gas Analyzer System for Metabolic Analysis Physiology (GASMAP) Gas Cylinder Assembly (GCA) Hand Grip Dynamometer (HGD) Inflight Blood Collection System (IBCS) Ingestible Temperature Monitoring System (ITMS) Instrumented Vest Assembly (IVA) Life Sciences Laboratory Equipment (LSLE) Microcomputer II Luminous Target Display (LTD) Magnetic Resonance Imaging (MRI) Device Medilog Sleep Research Recorder (MSRR) Oral Thermometer Payload General Support Computer (PGSC) Percutaneous Electrical Muscle Stimulator (PEMS) Performance Assessment Workstation (PAWS) Physiological Signal Conditioner (PSC) Pulmonary Function Facility (PFF) Rack Mounted Centrifuge Respiratory Inductive Plethysmograph (RIP) Suit Respirace Electronics Module (REM) Saliva Collection Kit Spacelab Refrigerator/Freezer Spacelab Thermoelectric Freezer (STEF) Superpocket Assembly Target/Subject Positioning Device Temperature and Humidity Monitoring System (THMS) Thermistor Recorder Temperature Monitoring System Thermoelectric Freezing Module (TEFM) Thermoelectric Holding Module (TEHM) Torque Velocity Dynamometer (TVD) Torso Rotation Experiment (TRE) Urine Monitoring System (UMS) Vacuum Interface Assembly (VIA)
STS-90/ Neurolab	Animal Enclosure Module (AEM) Botany Experiment Incubator (BOTEX) Medical Experiment System Research Animal Holding Facility Vestibular Function Experiment Unit Virtual Environment Generator (VEG) Visual Vestibular Investigation System Visuo-Motor Coordination Facility (VCF)

## Index of Expanded Hardware Descriptions

### **Actillum**

The Actillum is a wrist-worn activity/light storage center (32K bytes). It quantifies simultaneous motor activity and light exposure in a high-precision manner. It measures linear acceleration in the range of 0.1-g to 5-g, is resistant to spontaneous drops and contains a precision photo diode photometer which measures light exposure in the range of 0.01 to 10,000 lux. The sampling rates for the accelerometer and the light sensor are 20 samples per second and 1 sample per second, respectively. It is powered by two "1/2 AA" lithium batteries offering 350 to 500 hours of continuous operation. Dimensions are 7 x 3.8 x 2.2 cm and mass is 0.10 kg. A Nomex wrist strap with a removable gauze liner allows the crewmember to wear the Actillum on either the left or right wrist.

### **Animal Enclosure Module (AEM) (Basic Version)**

The Animal Enclosure Module (AEM) supports up to six 250-grams rats and fits inside a standard middeck locker with a modified locker door. It is composed of a stainless steel grid cage module, fan blowers, a layered filter system, interior lamps. Food bars are glued on cage walls. Total animal floor space is approximately 863 cm<sup>2</sup>. A removable divider plate provides two separate animal holding areas (if required). The AEM remains in the stowage locker during launch and landing. In orbit the AEM may be removed from the locker and the interior viewed or photographed through the clear Lexan cover which is over the cage; the AEM must be pulled out of the locker approximately three quarters of its depth to allow crew observation of the rodents. Temperatures are read from a built-in thermometer. The Main Breaker protects and distributes power to fan and lighting subsystems. Additional circuit breakers independently protect lights and fans in diagonally opposed corners to assure light and air circulation on each side of the AEM should one breaker fail. The AEM is moved into the Orbiter approximately 12 hours before launch and removed approximately 1 hour after landing. The original AEM unit was developed for the Student Shuttle Flight Program (SSIP) by the General Dynamics Company. Units flown initially utilized potatoes as a water source.

**Air Quality:** Cabin air is exchanged with the unit through a filter system. Four fan blowers, operated by a switch on the front panel, create a slight negative pressure inside the cage, causing an air sweep to pull animal waste products into a collection filter. Cabin air is drawn through the front panel inlet slots, then along the side plenum walls, to be directed through the inlet filter located at the rear of the AEM, into the animal habitat. High efficiency particulate air filters (electrostatic and phosphoric acid treated fiberglass pads) prevent any microbiological escape into the cabin atmosphere. Treated charcoal, within the unit, confines animal odors within the closed system. After exiting the habitat through the exhaust filter, located at the front of the unit between the rodent cage and fans, the filtered air is drawn through the fans into the cabin and directed by the air deflector. Air flow indicator ribbons are attached to both sides of the air deflector for visual confirmation of AEM air flow.

**Lighting:** The four internal lamps provide an average of 14 lux illumination and are controlled by an automatic timer to provide a 12-hour lighting cycle. The lamps are mounted two to a side in the rear corners of the AEM, between the animal habitat and inlet filter, and are covered with a clear cap to protect each lamp from animal debris and to contain glass if lamp breaks. Although the 12-hour cycle is fixed, the starting hours, minutes, and day/night sequence can be selected.

**Water:** The basic unit was not equipped with a drinking water system. Animals obtained fluids by eating potatoes which were placed in the cage.

**Food:** Standard rodent food bars are attached to four slide-in food bar plates inside the rodent cage. The food, a sterilized laboratory formula, is molded into rectangular bars (approx. 1.875 x 1 x 8 inches) accessible to the animals at all times during the mission.

**Upgraded Version Modifications:** After the Student Shuttle Flight Program, a water box, described above, was added to provide a better source of hydration. A major modification was made later to allow in-flight



refilling of this water box. This modification added connections on the front panel, appropriate controls and tubing to transfer the water being added to the water box. New fans were also installed to provide better acoustics and new inlet and outlet filters were provided for better odor control. Cloth mufflers, attached to the outside of the AEM, were also added in order to further reduce the middeck noise level. The inside cage divider was removed. Finally, a holder was made at the rear of the AEM to contain an Ambient Temperature Recorder (ATR-4) with holders for two remote ATR temperature sensors. New timers were also installed when it was determined that the originals were no longer available.

### **Aquatic Animal Experiment Unit (AAEU)**

The purpose of the AAEU is to provide a life support system for fishes and other aquatic animals in the Spacelab. AAEU consists of the main unit, Aquarium Package (A/P) for newts and Medaka fish, and Fish Package (F/P) for goldfish. A/P and F/P each have an independent life support system. The water in the AAEU is kept clean by filtration devices that trap waste materials from the animals. Oxygen circulates water at appropriate rates and the temperature is controlled independently. A water accumulator compensates evaporation.

Using this unit, scientists can study small aquatic animals for the duration of the mission. It permits observations of spawning, fertilization, embryonic stages, vestibular function, and behavior in microgravity. Animals, such as newts, live in four cassette-type aquariums, and there is a water tank designed for fish. A special life support system supplies oxygen, removes carbon dioxide and waste, and regulates temperature from 15 to 25 degrees C. The crew can view the animals through a window and access them via a port.

### **ARC Life Sciences Spacelab 3 Payload Composition**

Spacelab 3, rack 5, is a single portside rack (Ames Single Rack -ASR). It contains a primate RAHF which houses and provides life support for four squirrel monkeys, each within their individual cages. (Due to complications preflight, only two monkeys were actually flown. These two monkeys were both unrestrained and free to move about their cages, as opposed to be restrained.) Spacelab 3, rack 7, is a double portside rack (Ames Double Rack-ADR). It contains a rodent RAHF which houses 24 rodents and that RAHF is equipped with a 16mm camera/mirror system to enable photography of the rodents contained within the bottom four cages. These photographic images are reflected by the mirror system to the camera mounted above and the camera is controlled by a camera control box which has preset switches that can be and are changed on-orbit.

Four of the rodents are implanted with biotelemetry transmitters which permits four signals to be received by an installed cage antenna and transmitted via cabling to a Biotelemetry System (BTS).

The right side of the ADR contains the BTS receivers and demodulators, a Dynamic Environment Measurement System (DEMS) which measures vibration, acoustics and acceleration, two condensate collectors (one for the rodent RAHF and one for the primate RAHF), an intercom remote panel and the Life Sciences Laboratory Equipment (LSLE) microcomputer which accepts data from the BTS systems and transmits that data to the Spacelab High Rate Multiplexer (HRM) for transmission to the ground.

### **Astroculture™**

The Astroculture experiment flying on this mission contains three subsystems that address these issues and provide superior environmental control for plant growth in an inexpensive and reliable spaceflight package. First, the experiment's water and nutrient delivery system uses porous tubes with different pressures to ensure a proper flow through the rooting matrix. This system has already proven itself to be effective during long-duration flights in the micro-gravity environment. Second, the efficient subsystem for controlling moisture in the growth chamber humidifies and dehumidifies the air without needing a gas/liquid separator, which is required by all other systems currently in use, to recover the condensed water. Third, the lighting subsystem uses light-emitting diodes (LEDs) to provide high levels of light within the limits of electrical power available on orbit and with greater safety than any other light sources currently used by space-based plant growing facilities. The experiment package is sealed, with

cooling provided by an experiment heat exchanger and carbon dioxide (necessary for photosynthesis) supplied from a storage tank.

### **Autogenic Feedback Training Experiment (AFTE) System (SL-3 version)**

The Autogenic Feedback System-1 is a self-contained, battery-powered, ambulatory, physiological-monitoring system. It can continuously monitor, display, and record up to nine channels of physiological data continuously for up to seven hours on a single cassette tape and change of batteries.

### **Autogenic Feedback Training Experiment (AFTE) System (SL-J version)**

The Autogenic Feedback System (AFS-2) is a lightweight, self-contained, battery-powered ambulatory physiological monitoring system. It can continuously monitor, display and record 9 channels of physiological data for up to 12 hours on a single change of batteries. The Belt Assembly features both a Treatment Mode and a Control Mode. The Treatment Mode permits display of physiological data on a small wrist display while the Control Mode allows only system status and malfunction indications to be displayed. Acquired data is stored on a standard audio cassette using special instrumentation tape.

The AFS-2 system may be divided into three general subsystems: the Sensor Group, Garment and Cable Harness Assembly, and the Belt and Recorder Assembly.

**Sensor Group:** Through a unique combination of sensors and transducers, the AFS-2 can acquire skin temperature (70-99.9 degrees F  $\pm$  1 degree F), blood volume pulse (1-200  $\pm$  0.5 ), skin conductance level (0.5-50  $\mu$ MHOs  $\pm$  2 percent), electrocardiography (40-180 beats/minute), respiration (4-60 breaths/minute), and acceleration in three axes ( $\pm$ 0.25 G  $\pm$  5 percent). These signals are transferred to the Belt Electronics for signal conditioning prior to recording.

**Garment Assembly:** The Garment Assembly consists of a Garment, a Cable Harness, Sensors and Transducers, and a Wrist Display Unit. The garment is a cotton jumpsuit featuring velcro attachment points to secure the Cable Harness. The Garment also serves as a support structure for the various system sensors and transducers. A custom-designed liquid crystal display is attached with velcro to the left sleeve of the AFS-2 garment. The Wrist Display Unit not only provides display of physiological data, but also indicates malfunctions and low battery conditions. Data and power for the Wrist Display Unit are provided by the Belt Electronics via the cable harness.

**Belt and Recorder Assembly:** This group consists of a Belt Electronics Package, a Battery Pack, and a TEAC Data Recorder. The Battery Pack provides power for the entire system using four alkaline 9V transistor-type batteries. The TEAC Data Recorder, a modified nine-channel TEAC HR-40J FM, records analog and digital signals from the Belt Assembly. Data and power for the Data Recorder are provided by the Belt Electronics via the TEAC Interface Cable.

### **Baroreflex Measurement System**

By applying either suction or pressure to the neck, the carotid baroreceptors can be stimulated. The change in R-R interval produced by a given change in neck pressure is measured.

The centerpiece of this system is a neck chamber made of silicone rubber molded to fit the contour of the anterior three-fourths of the subject's neck. There is a Silastic rubber diaphragm inside the chamber which seals against the neck when pressure is applied. The chamber is connected by means of flexible tubing to a bellows driven by a stepping motor. Bellows movements are controlled by a microprocessor, which also analyzes pressure changes within the system, and analyzes ECG (R-R interval) changes. The system works on the principle that a vacuum applied to a chamber encircling the neck slows heart rate by stimulating the carotid baroreceptors. Pressure changes are transmitted from outside the neck to internal structures; therefore, carotid distending pressure is altered, the carotid artery stretches, baroreceptor nerves change their firing rates, and a baroreceptor-cardiac reflex response is produced.

The neck chamber system kit contains eight custom-fitted neck chambers (a backup is carried for each crewmember), two umbilicals and a backup digital display module (DDM). The neck chamber system is worn by the test subjects during experiment operations.

The pressure system consists of two microprocessor controlled, stepping motor-driven bellows and a calibration canister. Either of these bellows systems is able to furnish a complex stimulus to the neck chamber system between the pressures of +40 and -65 mmHg. The pressure system is calibrated with a pressure gauge.

### **Bicycle Ergometer**

The Bicycle Ergometer is an exercise bicycle that provides a quantitative measure of work done by a subject for experiments evaluating the effects of 0-g upon the cardiovascular system.

The equipment consists of a variable workload cycle ergometer, driven by hands or feet, that is controlled by the subject's heart rate, manual adjustment or computer control through the use of an ergometer control box mounted to the side of the ergometer. The workload is 10 to 350 W + 5 W, pedal speed is 40 to 80 rpm, and the heart rate control range is 40 to 200 bpm.

### **Biorack**

The Biorack is a multi-purpose facility for experiments in cell and developmental biology and radiation biophysics. It had its first flight on the German Spacelab Mission D-1 in 1985. The main elements of the Biorack are incubators, a cooler/freezer and a glovebox. It also includes special canisters for transporting and maintaining sensitive biological samples under a well-defined thermal environment. Experiments are generally housed in small experiment containers of standard dimensions. The experiment containers are provided to the investigators, who accommodate their biological samples, nutrients, etc. according to their specific requirements.

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**Incubators:** The incubators can be set at an accurate temperature in the range of 18 to 30 degrees C, depending on the type of incubator. Two centrifuges are included in each incubator to "simulate" a 1-g environment. Control samples, identical to those being exposed to microgravity conditions, are placed in these centrifuges. Comparison of these two sets of samples, after completion of their processing in the incubator, permits the microgravity and radiation-environment effects to be identified.

**Cooler/Freezer:** The cooler/freezer is a combined unit that allows the maintenance of biological samples at temperatures that inhibit their metabolism. The cooler is capable of maintaining samples just above the freezing point (4 degrees C), and the freezer section can conserve samples at temperatures as low as -15 degrees C.

**Glovebox:** The glovebox is a small working area for handling and observing biological specimens. The observations can be made through a microscope connected to photo, film, or TV cameras.

### **Biotelemetry System (BTS)**

The Biotelemetry System (BTS) monitors physiological functions of mammals on board the Spacelab. This rack-mounted system is designed to be used primarily with the Research Animal Holding Facility (RAHF). Each unit of the BTS can monitor one animal for one to four physiological parameters. Transmission of data from the BTS data-handling system to Spacelab data systems is accomplished through a Life Sciences Laboratory Equipment (LSLE) Microcomputer.

**Implantable Sensors and Transmitter:** The implants for SL-3 included a transmitter as well as the sensors for deep-body temperature, heart beat count and signal strength which are sampled once a second and heart rate (ECG) which is sampled at 320 times per second. The range of the transmitter is at least one foot. Implantation typically occurs three weeks prior to launch.

**Antenna/Receiving System:** The antenna is capable of being installed within one cage of the RAHF and is connected via cables to a receiver/demodulator system compatible with the BTS Data Handling System. Sensor data are transmitted from the implant to these antennae within selected rodent cages. A pulse interval modulated FM radio signal is received from each animal cage being monitored.

The four receivers, two demodulators, four QRS signal conditioners and one power supply comprise this part of the Biotelemetry (BTS) system. This part of the system is mounted in a rack space next to the rodent RAHF.

**BTS Receivers:** These receivers are designed to distinguish between proper transmitter signals and outside RF signals. Each receiver has controls suitable for interfacing with an associated demodulator system. The Automatic Frequency Control (AFC) switch enables the automatic frequency control function. The display switch enables the numerical LED display which is tuned to a specific frequency between 88-108 MHz. A tuner knob located in the lower center part of the receiver is used to adjust the signal strength and center tune the frequency of the transmitter. The left 10 diodes above the LED display verify optimal signal strength. The right 10 diodes and the dropout light located on the left side of the receiver verify correct adjustment of signal frequency. Squelch control is preset to minimum but can be adjusted on orbit. The level, logic and video output connections are used for test only. Output signals from these receivers are sent to the demodulators.

**Demodulators/QRS Boards:** The demodulator is designed to accept the received signal and encode the ECG and deep body temperature information from the pulse train and convert them to analog outputs. A QRS board (not shown, contained within receiver module) receives the waveform, a portion of the ECG, from the receiver to enable counting of heart beats. The QRS board is an event accumulator that counts heart beats to 255 and then resets to zero to resume accumulation. This heartbeat count is sent to the Life Science laboratory Equipment (LSLE) microcomputer with the ECG and deep body temperatures. In the event of a signal dropout, the demodulator is capable of holding the last value received for temperature until an adequate quality signal is again received.

### **Body Mass Measurement Device (BMMD)**

The BMMD (Body Mass Measurement Device) measures the mass of human subjects in zero-gravity.

Body mass determinations are made using a linear spring / mass pendulum platform. The mass measured determines the period of the pendulum. The period is electronically timed and is converted to a mass measurement. The equipment consists of a frame, a seat, springs, a release and lockout mechanism, specimen restraint, and an electronics module with display system. The BMMD comprises a Mechanical Subsystem and an Electronics Subsystem. This device is completely self-contained, with the exception of requiring a DC power source (nominal 28 volts) and a plane stable supporting surface. Immediately adjacent to the seat is the display face of the Electronics Subsystem.

### **Cardiopulmonary Rebreathing Unit (CRU)**

This hardware is used to: 1) allow the subject to breathe cabin or test gas, and 2) simultaneously monitor flow rate and inspired/expired air content.

This item consists of a rebreathing bag, a system of electronically and pressure operated valves controlled by the CCU, a mouthpiece, a probe and capillary line leading to the GAMS, a flowmeter in the breathing pathway, thermistor, indicator lights, and control switches. During the experiment the rebreathing bag is filled with a known volume of test gas. The valves control the filling of the bag and also select whether the subject breathes cabin air or test gas.

During rebreathing, no cabin air enters the air system. The air system is comprised of the bag, valves, mouthpiece, and subject. After rebreathing, the valves switch the subject to cabin air. The rebreathing bag then is exhausted by exposure to space vacuum. The bag has a special spring valve, to facilitate complete emptying.

The mouthpiece holder accepts a mouthpiece through which the subject breathes. When the subject uses the mouthpiece an airtight seal is formed. The GAMS probe is located in the breathing pathway and samples breathing air, diverting 60 ml/min. to the GAMS via the capillary line.

The CRU is mounted on top of the bicycle ergometer, positioned between the shoulder restraints. The CRU receives signals from the CCU to close the air system to cabin air and open it to the rebreathing bag, at the appropriate time after subject switch activation. The CRU also switches the subject back to cabin air at the end of the rebreathing period.

### **Cell Culture Chamber (NASDA)**

The NASDA provided Cell Culture Chamber is an aluminum, petri-dish-like chamber 101 mm in diameter and 32 mm high. The interior of this chamber is coated with PTFE. A honey-combed matrix is inserted into the base of the chamber in order to provide structural support to the agar/cells. This honeycomb matrix is constructed from an unspecified aromatic polyamide. In order to provide for gas exchange, the top of the chamber has a 45µm, polysulfone, gas-permeable membrane. This membrane is a commercially available filter.

### **Cell Culture Kit (CCK) - Plant Fixation Chambers (PFCs) (NASDA Life Science)**

The Plant Fixation Chambers (PFCs) were provided by NASDA. They are aluminum, petri-dish like containers which are approximately 100 mm in diameter by 35 mm high. Each chamber has a 15 mm septum port which extends 22 mm above the top of the container. These containers are completely sealed. The PFCs allow plant cells exposed to space flight to be fixed on orbit by insertion of a chemical fixative via syringe through the septum port. The fixative used was a 3% glutaraldehyde (balance water) solution. 20 ml of fixative was contained within each chamber.

### **The Commercial Generic Bioprocessing Apparatus (NASA)**

(CGBA) is a multi-purpose facility that allows scientists to study biological processes in samples ranging from molecules to small organisms. The CGBA payload replaces a standard middeck locker, which can be flown in the Space Shuttle middeck, Spacelab, or in Spacehab. Samples are contained in a Fluid Processing Apparatus (FPA), a device that is essentially a "microgravity test tube." An FPA is a multi-chambered glass barrel that allows sequential mixing of three fluids. Eight FPAs are housed in a Group Activation Pack (GAP). The CGBA locker provides a uniformly temperature-controlled (37 °C) volume for nine GAPs, data acquisition and control electronics, and optical density measurement capabilities (565 nm) for up to eight FPAs at a time. GAPs also can be stored at ambient temperature in middeck lockers or in the Spacelab module. The CGBA locker and its samples can be loaded as late as 18 hours before launch to maximize viability of the biological samples. Bioprocessing reactions can be initiated using predetermined mixing protocols. Multiple-step reactions involving sequential mixing of fluids are possible for phased processing. Simple optical monitoring of turbidity changes is possible. This capability is a major innovation in the study of biological processes in space. A crewmember can activate experiments by turning a crank on the GAP, thereby initiating the first fluid mixing process. Later in a mission, experiments can be terminated in a similar fashion. Some samples can be monitored for brief periods repeatedly throughout the mission. Both data taken on orbit and the returned samples provide the basis for experimental analyses.

### **Dynamic Environment Measuring System (DEMS)**

The Dynamic Environment Measuring System (DEMS) is an instrumentation package that monitors and records Spacelab vibration, acoustics, and acceleration levels during launch and reentry. Data are used to monitor the stimuli various biological systems experience under launch and reentry loads. A microphone, a

triaxial-vibration sensor unit, and a triaxial-accelerometer unit function, respectively, as the acoustic, vibration, and acceleration transducers. One other device, the DEMS MET (Mission Elapsed Time) Slow Code Generator, converts the orbiter's pulse width modulated time code (100 Hz) to an amplitude modulated "slow code" (10 Hz) which is recorded by the DEMS tape recorder. The DEMS Signal Conditioner passes only certain frequency ranges from the sensors to the recorder. The axes and frequency ranges of the various signals are as follows:

Acceleration: X,Y, and Z axes, low frequency only (DC-20 Hz) for three unique signals.  
Vibration: X,Y, and Z axes, low and high frequencies (20-160 Hz, 50-2,000 Hz) for six unique signals.  
Acoustics: low and high frequencies (20-160 Hz, 50-6,000 Hz) for two unique signals.  
MET Slow Code: low frequency (10 Hz) for one unique signal.

During launch and reentry, the DEMS cassette recorder collects the signal on two cassette tapes, seven tracks per tape (the eight channel is not used). The twelve DEMS signals are distributed on the two cassette tapes within the DEMS; X-acceleration and MET signals are recorded on both tapes to help synchronize the two separate groups of data. The DEMS is designed to activate automatically at launch and reentry, but can also be manually controlled. Once activated, the DEMS records data automatically for ninety minutes.

The DEMS, located in Spacelab rack 7 adjacent to the RAHF, measured three-axis vibration, three axis acceleration, and acoustic noise levels. The unit was turned on by manual switch activation by the crew in the aft-flight deck prior to launch. Recorded tapes of the ascent were removed by the crew during orbit and exchanged with new tapes to record conditions associated with reentry and landing. For data reduction, digital information on the tapes was decoded using a special cassette playback unit. The output of the cassette unit was fed, one cassette at a time, into a 14-track recorder. Along with the MET pulses, the most apparent and readable signals were acceleration values with respect to the gravity vector: the X-acceleration at launch (Shuttle length) and the Z-acceleration at descent (Shuttle height). DEMS information was correlated with reactions of the animals and performance of the hardware.

### **Frog Embryology Unit (FEU)**

The Frog Embryology Unit (FEU) is designed to provide a habitat for four female frogs as well as groups of developing embryos. Ventilation air and a temperature-controlled environment of 17 degrees C - 22 degrees C  $\pm$  0.25 degrees C is provided. A centrifuge inside the FEU provides a simulated 1-g Earth environment, and can accommodate up to 28 Egg Chamber Units (ECUs). A separate compartment inside the FEU provides exposure to microgravity conditions for an additional 28 ECUs. When combined, these systems provide the researcher with a capability for simultaneous side-by-side experiments consisting of both a 0-g "treatment" group and a 1-g "control" group.

### **Frog Embryology Unit (FEU) (SL-J version)**

The Frog Embryology Unit (FEU) is designed to house four female frogs, which are provided with ventilation air and a temperature-controlled environment of 18 degrees Celsius for the ovulation phase of the experiment. This temperature is reset to 21 degrees Celsius after egg fertilization in the General Purpose Work Station (GPWS). A 1-g centrifuge is part of the FEU and provides a simulated on-Earth condition. A zero compartment in the FEU provides exposure to microgravity conditions for two racks of Egg Chamber Units (ECU). Another part of the FEU is a chamber to house an Adult Frog Box. Completing the FEU system is a mainframe control panel and a power conditioning unit with front panel.

Power and Control Systems: The Power Conditioning Unit (PCU) provides 28 volts DC from Spacelab and distributes this power to the various sub-systems. The PCU switches and indicators provide for set-up, monitoring and operation of the unit. The six sub-systems controlled by the Pulse Code Modulation (PCM) include the thermoelectric temperature control system, the air circulation fans, the adult frog box air pumps, the centrifuge, the temperature monitoring system and the digital PCM electronics. The main power switch provides 28 volts DC to all systems; however, the T.E. MAIN power switch must be placed in the ON position to power the thermoelectric unit.

The Mainframe Control Panel is divided into four subsections: the Thermoelectric Unit (TEU) control, the centrifuge control, the data acquisition control and the temperature monitor. The TEU provides heating and/or cooling as required by the set point on the thermal unit panel and as modified by the proportional controller that modifies the set point. The TEU interfaces with the Spacelab coolant loop through two disconnects in the rear of the FEU. The centrifuge control allows centrifuge run or stop operations and indicates status. Automatic sensors stop the centrifuge when the door is opened to permit changing of Egg Chamber Units (ECU). A power cut-off switch engages when the door is opened and may be manually disengaged in order to manually rotate the centrifuge for experiment work. The data acquisition panel permits the following three alternatives: Normal operation of all 12 temperature channels, High Cal operations with temperature sensor channels fed into the signal conditioners reading the high range and Low Cal operations with temperature sensor channels fed into the signal conditioners reading the lower temperatures. The temperature monitor permits individual display of any of the 12 temperature channels on a liquid crystal display. This permits a check of the calibration of the sensors.

Frog Box Chamber/Centrifuge/0-g Stowage: The adult frog box chamber holds the frog box with four adult female frogs that will provide eggs for the experiment. It is connected at the rear of the compartment with a quick disconnect air supply to sustain the frogs in the box. The centrifuge provides an artificial gravity force of 1-g for selected egg chambers. It has a double row of slots, color-coded to match the egg chambers. The 0-g stowage compartment is a holding chamber to maintain embryos in the microgravity environment of the orbiter; it houses two racks, A and B.

### **Gas Analyzer System for Metabolic Analysis Physiology (GASMAP)**

The Gas Analyzer System for Metabolic Analysis Physiology (GASMAP) device is used to monitor and analyze inhaled and exhaled breath streams to determine their gas concentrations. The primary gases of interest are nitrogen (N<sub>2</sub>), oxygen (O<sub>2</sub>), carbon dioxide (CO<sub>2</sub>), argon (Ar), acetylene (C<sub>2</sub>H<sub>2</sub>), sulfur hexafluoride (SF<sub>6</sub>), helium (He), and carbon monoxide (C<sub>18</sub>O).

The GASMAP flight hardware consists of two components: an analyzer module and a calibration module, both of which are housed in drawers inside the Spacelab. The analyzer module contains all the sensor and electronic hardware of the GASMAP. The major sub-assemblies of the analyzer module are the Random Access Mass Spectrometer (RAMS), the Roughing system, the Gas Delivery system, the Interface Shell (IS) computer and the power connection. The module is controlled via the keypad and LCD display of the front panel, or via a laptop computer.

The Random Access Mass Spectrometer (RAMS) is the largest assembly of the analyzer module. Through software control, the RAMS can measure molecular mass-to-charge ratio in the range of 1 to 250 AMU (atomic mass unit) with a resolution of 1 AMU and a sensitivity down to 250 ppm (parts per million). A Single Board Computer resides in the RAMS and is dedicated to performing housekeeping functions and calculating gas concentrations. The gas data are sent out on ten analog outputs, reading gas and range. In addition, data transfer through two computer ports is available. The analog RAMS readings are displayed on the front panel of the GASMAP device and a second signal is prepared for data downlink by the Interface Shell computer.

The functional components of the RAMS include a gas inlet valve, an ionizer, a mass filter, a collector, an ion pump, a roughing system and a gas delivery system. The gas inlet valve controls the inlet of small amounts of gas into the ionization chamber (in the range of microliters), independent from the outside pressure. In the ionization chamber the gas molecules are ionized by electron bombardment and released to the mass filter system, which consists of electrically charged rods. The electrons are neutralized when brought into contact with the rods. This allows the calculation of (gas) concentrations. The process must be repeated separately for each analyzed gas.

The Gas Delivery system provides constant gas sample flow rates in the range of 10 to 150 cc/minute to the RAMS for analysis. The system contains a micron screen to protect the analyzer from debris and liquid and a flowmeter to provide the desired target flow. To eliminate any pulsating effects, a surge chamber is added just before the gas enters the RAMS through the inlet valve. The Roughing system provides the necessary hardware and vacuum interfaces to pump down the analyzer in the event of a loss of vacuum,

which is necessary for nominal operations. The Interface Shell computer also controls the GASMAP subcomponents, acquires data, and transfers data to display devices, to the rack controller, and to analog outputs.

The calibration module is compatible with the analyzer module and is used to calibrate the RAMS readings on a regular schedule. Three cylinders, filled with a known gas mixture, are installed in the calibration device. By knowing the mixture, the readings of the GASMAP system can be compared and adjusted if necessary.

### **Gravitational Plant Physiology Facility (GPPF)**

The Gravitational Plant Physiology Facility (GPPF) occupies a Spacelab double rack and is designed to support plant experiments in space.

The GPPF consists of a Mesocotyl Suppression Box (MSB), a control unit (CU), a culture rotor (CR), a test rotor (TR), two Video Tape Recorders (VTR-F and VTR-G), a Plant Holding Compartment (PHC), a Recording and Stimulus Unit (REST), and a plant cube support panel.

**Control Unit:** The control unit (CU) manages power to experiment hardware and controls the functions of the rotors, cameras, REST, etc. It also has a TV monitor system that displays such functions as rotor and REST speeds and temperature. Commands to the system are entered on a panel keyboard with a one-line, 24-character display that shows messages prompted or for confirming inputs. These commands initiate inflight activities. The one-line display and video monitor also generate/display warning messages such as over temperature, door opened, etc. It also includes four circuit boards behind a front panel hatch.

**Culture Rotor:** The culture rotor (CR) is located immediately beneath the control unit. It contains two 1-g centrifuges (rotors) that simulate Earth gravity. Each rotor contains 16 plant cubes. The rotors are individually controlled (start and stop) by the control unit. Plant cubes are placed on these rotors prior to their transfer to the Mesocotyl Suppression Box (MSB), the Test Rotor (TR) or the Recording and Stimulus Chamber (REST).

**Test Rotor:** The test rotor (TR) is located directly beneath the culture rotor. It operates within the range of zero gravity to 1.5-g. The system includes an internally mounted infrared-sensitive video camera head. The plant cubes rotate on the rotor and move in succession across the video camera field of view to permit time-lapse video recording of plant bending. The control unit commands the rotors to operate in a slow-scan mode, which is followed by a g-pulse/time stimulus and a return to the slow scan mode when video recording of the response to the stimulus takes place.

**Recording and Stimulus Chamber:** The Recording and Stimulus Chamber (REST) provides the capability for time-lapse infrared video recording of plants in four plant cubes, before and after an exposure to blue light. The light pulse is provided by a 10-watt tungsten filament lamp. A camera and recorder, controlled by the microprocessor, take nine-second pictures every ten minutes.

**Video Tape Recorders:** Two redundant video tape recorders (VTR-G and VTR-F) are located on the side of the rack above the Recording and Stimulus Chamber (REST). They are used to record images from the REST and from the Test Rotor (TR) cameras. They record the same information to ensure successful data collection.

**Mesocotyl Suppression Box:** The Mesocotyl Suppression Box (MSB) is located in the upper left of the GPPF double rack. It is used only with oat seedlings that are exposed to a red light spectrum for up to ten minutes. The red light permits the seedlings to grow straight, enhancing viewing. If no red light were used, the mesocotyl tissue of the plants would undergo extensive growth and cause bending and elongation. Four soil trays containing seedlings are removed from their plant cubes and loaded into the MSB at one time. The empty plant cubes are attached temporarily to the Cube Support Panel (CSP) directly above. The MSB features a power switch, a timer to regulate the exposure of red light and indicator lights.



**Plant Holding Compartment:** The Plant Holding Compartment (PHC) is located in the lower left side of the double rack. It is thermally regulated and contains a seed planting kit, gas sampling syringes, rotor counterweights, and plant cubes. The seed planting kit contains oat and wheat seeds wrapped in aluminum foil, a dibble to plant the seeds in soil tray wells and a seed planting fixture to aid the planting process.

### **Hand Grip Dynamometer (HGD)**

The Hand Grip Dynamometer (HGD) is a device used to measure any applied compressive force. It is used to measure grip strength capabilities through the establishment of a muscle force/time relationship. The HGD is a stowable, hand held device that is battery powered. It is able to measure forces from 0 to 100 pounds, and its outer dimensions are approximately 207 x 89 x 32 millimeters with a weight of about 900 grams.

The HGD consists of two components, the handgrip module and the conditioner module. The load cell arrangement of the handgrip module generates a voltage signal when a compressive force is applied. The signal is transferred to an amplifier via a signal and power transfer cable and from there to the LSLE Microcomputer-2 for recording.

### **Inflight Blood Collection System (IBCS)**

The Inflight Blood Collection System (IBCS) is a system designed to collect blood samples from crewmembers in flight. The system is composed of Flight Day Assemblies and Work Trays. The trays include laboratory blood drawing items such as catheters, infusion sets, various sizes of vacutainers, needles, saline syringes, etc. The use of needles has been minimized by replacing sharp needles with blunt tipped plastic cannules and blunted needles where possible (sharp needles are only used for initial venipuncture).

The IBCS contains four different types of experiment support kits. These items are used in the collection and processing of blood samples for Spacelab experiments. These kits include:

1. Blood Collection Kit (equipment required for blood collection on each sampling day)
2. Blood Spares Kit (vacutainers, butterfly infusion sets, and syringes for contingency blood draws)
3. Blood Work Kit (slides, hematocrit tubes, hematocrit centrifuge, etc. for hematology workups)
4. Accessories Kit (heparin and small vacutainer tubes needed for sequential blood draws using indwelling catheters).

Preassembled blood collection components are prepackaged and sterilized on the ground for inflight use. Wrist bands are worn by the crew to protect the inserted catheter between blood draws. No sharp objects are exposed and all glass is covered with Teflon tape and shrink tubing to prevent shattering. All IBCS items are restrained within cloth and/or foam assemblies. A glove container is used to dispense gloves worn by the crew during blood collection activities. The configured assemblies are stowed in a middeck or Spacelab stowage locker during flight.

### **Ingestible Temperature Monitoring System (ITMS)**

Body temperature is measured using the Ingestible Temperature Monitoring System (ITMS). The ITMS consists of an ambulatory recorder unit with an attachment belt and pouch, antenna harness and disposable temperature sensor. The belt-mounted recorder is connected to the antenna coil worn on the subject. The recorder receives the temperature signals transmitted by the ingested temperature sensor, displays the temperature on a two-line liquid crystal alpha-numeric display, and stores up to 4500 individual time and temperature readings in 16K RAM memory. Selectable features such as sampling rates, temperature scales and limits, filter modes and other settings are keypad programmable. The unit operates on one 9 volt alkaline battery which provides approximately 12 hours of use. The display will flash a warning and an audible tone will sound when the battery is low or when a sensor may have been passed. The recorder dimensions are 20.3 x 13.7 x 7.6 cm and the mass is 1000 grams.

The ingestible temperature sensor is a small electronic device that utilizes a temperature sensitive crystal to sense the core body temperature and transmit that temperature to a receiver antenna that is within approximately 25 cm. The sensor is intended to be swallowed. The entire sensor is totally encapsulated first in an inner epoxy shell and then in a dimethyl polysiloxane silicone outer coat. Power is provided by a non-rechargeable silver oxide mini-battery which provides 100 hours of operation. The sensor can be turned on and off by means of an enclosed magnetic switch. The sensors are stored with magnets attached in order to keep the batteries turned off. Prior to use, the battery is activated by removing the small magnet. The sensor dimensions are approximately 16mm long and 10mm in diameter and the mass is 3.0 grams.

## **Jellyfish Kit**

Jellyfish kits contain the necessary materials to maintain jellyfish during flight. The kits are maintained in the Refrigerator Incubator Module (RIM) to provide a constant 28° environment for the specimens during flight. Various hardware is used to support various experiment activities. These include: 1) commercially obtained polystyrene flasks utilized for jellyfish groups requiring inflight filming; 2) a passive bagging system used to maintain those specimens requiring no inflight manipulation; and 3) a bagging system with attached chemical delivery system for specimens requiring inflight treatments. This experiment consist of four distinct kits.

**Jellyfish Bags/Kits:** Jellyfish are maintained in these bags filled with Artificial Sea Water (ASW), at a concentration of 1:3 ratio of air to solution. Kapak bags of polyester with polyethylene lining are utilized. Bags are carefully cleaned and tested for biocompatibility prior to use. Lithium fluoride (LiF) radiation rod dosimeters are added to 6 of the 18 bag configuration in Kit #1 before heat-sealing the bags. Kit #1 contains nonoperative single compartment bags that do not require crew operation on orbit. Kit #2 contains 8 multicompartiment syringe/bag assemblies with one to three syringes attached. Each syringe bag has two outer bags for containment and are individually tetherable. Kit #3 is empty and is stowed in the Spacelab refrigerator. The fixed specimens from kit #2 are transferred to the empty kit during the last in-flight procedure and returned to the refrigerator. Kit #4 contains the small culture flasks containing ASW and Jellyfish. The flasks are made of optically clear polyethylene and are used for filming Jellyfish swimming patterns in zero gravity.

**Chemical Delivery Systems (CDS):** Chemical Delivery Systems (CDS) were developed for the introduction of chemicals to the jellyfish in space. Kapak bags of polyester with polyethylene lining were modified for attachment to syringes via plastic housings. These are carefully cleaned and tested for biocompatibility before launch. Three days before flight, chemicals are placed in small plastic bags inside the syringe barrels of the CDS. Iodine and thyroxine are injected into the bags containing the animals during the flight, to achieve a final concentration of 10 to the -5th M in ASW. The CDSs are contained within inner and outer plastic bags to achieve triple containment.

For SLS-1 and using kit #3 hardware, six groups of jellyfish were treated eight hours after launch with iodine or thyroxine by pushing the plunger of the syringes of the CDSs, thus releasing the inducers into the bags. On the eighth day of flight (FD 8), four of these groups were fixed by injecting the fixatives into the bags. Glutaraldehyde (3% concentration) and cacodylate buffer were injected simultaneously using the CDSs.

## **Life Sciences Laboratory Equipment (LSLE Microcomputer)**

**Biotelemetry (BTS) Data Handling System:** The Biotelemetry System (BTS) animal ECG rate is up to 320 samples per second; the other parameters are sampled at a rate of one sample per second by the LSLE Microcomputer. Data can be stored for later transmission or down-linked to Earth by radio transmission in realtime or near-realtime.

**Life Sciences Laboratory Equipment (LSLE) Microcomputer:** The JSC developed LSLE Microcomputer is designed as a stand-alone computer for use with flight experiments onboard the Shuttle. A flexible system design allows the experimenter to use the microcomputer to accomplish a variety of experiment computer operations, by interfacing with Spacelab data systems for telemetry and/or onboard interaction. It is

designed to assemble and format data into uniform major and minor frames for transmission through the Shuttle high rate multiplexer (HRM) to the ground. During SL-3, the microcomputer assembled, formatted and time-coded the BTS data for HRM transmission, after converting the signal from analog to digital. It is operated only during orbit, and was activated by the crew via a front panel switch. This is the only switch manipulated on-orbit and activation is verified on the RUN LED displaying four sevens (7777) when the switch is turned on. It is turned off following deactivation of the Biotelemetry System (BTS).

### **Lower Body Negative Pressure Device (LBNP)**

The lower body negative pressure device provides a controlled, measured orthostatic stress to the cardiovascular system.

This item is configured as a cylindrical chamber made of anodized aluminum, with nominal measurements of approximately 51 cm in diameter and 122 cm in length. The cylinder separates longitudinally to provide access to the legs and to provide ease of installation of the leg band; closure of the cylinder is effected by bringing the two parts together and fastening with a Marmon clamp.

To maintain negative pressure within the chamber, movable superior and lateral iris-like aluminum templates, installed around the elliptical opening, are adjustable to fit snugly to the subject's lower waist at the iliac crests.

An adjustable padded post, which serves as a saddle or crotch restraint, is located within the chamber. It can be adjusted headward or footward so that the iliac crests of the subject are at the level of the metal templates.

The movable upper torso restraint assembly supports the person's upper torso while his/her lower body is within the LBNP Device. It retracts to a stowed position beneath the chamber when not needed. When deployed, it extends outward from the LBNP Device opening for 63.5 cm.

Decreased pressure within the device is provided by a vacuum plenum.

Safety features include a quick-release valve, easily accessible to subject and observer, and an automatic mechanism to prevent negative pressure from exceeding 65 mm Hg.

Pressure within the LBNP Device is vented to the room via the vacuum release valve. The pressure is maintained by setting the vacuum regulator at 0 to 50 mm Hg below ambient pressure.

### **Magnetic Resonance Imaging (MRI) Device**

Magnetic Resonance Imaging (MRI) is a technique that allows imaging of the interior of the body without the use of ionizing radiation. MRI technology is based on the fact that the nuclei of certain atoms, when placed in a magnetic field, will tend to align with the magnetic field. This is true in general of any nucleus with a non-zero magnetic moment, but hydrogen is the element used almost exclusively in medical applications. This is because of its abundance in biological tissues and large magnetic moment that makes it by far the easiest element to image. Several other biologically important elements (carbon, oxygen, and calcium) do not have a magnetic moment and therefore cannot be used in MRI.

In the presence of a strong magnetic field, the hydrogen nucleus can be likened to a top precessing about the gravitational field; the nucleus precesses about the applied magnetic field of the magnet. This precession has a frequency that is determined by the strength of the magnet and the magnetic moment of the nucleus that is characteristic of a particular element. For magnets used in medical imaging this frequency is typically in the range of FM radio waves. By controlling the magnetic field and the frequency and phase of the radio frequency (RF) pulses, images can be obtained in any desired orientation. Information regarding a particular part of an object is obtained by applying magnetic field gradients (which are small relative to the main field) so that the hydrogen in different slices will precess at different, but known frequencies. By applying RF pulses at a particular frequency, the nuclei in a particular slice can be excited. As the energy from this slice is dissipated, a receiver measures the resulting signal to obtain

information unique to this region of the object. Image contrast is achieved by varying the sequence and types of RF pulses. For each image, a series of pulses are required (typically 256) with a period between the pulses (typically 1 second) to allow the system to return to its original state.

The decay characteristics of the MRI signal are determined by the chemical and physical state of the hydrogen. This property allows to easily distinguish between various tissues such as fat, muscle and spinal disks, and by adjusting the imaging parameters the sequence for the tissue of particular interest can be optimized.

### **Medilog Sleep Research Recorder (MSRR)**

The Medilog Sleep Research Recorder (MSRR) system consists of a "belt pack" which is connected to a sleep cap with eight electrodes. The recorder is designed for nine channel, multi-parameter, ambulatory monitoring. Eight channels of physiological data can be recorded from four electroencephalogram (EEG) electrodes on the skull, two electro-oculogram (EOG) electrodes which will measure lateral eye movements (LOC and ROC), and two chin electromyogram (EMG) electrodes. The remaining channel is used for binary clock signals, automatically taken from the recorder's Real Time Clock, and subject initiated event markers. Recordings can be played back postflight using a replay and display system.

The dimensions for a commercial recorder unit are 146 mm x 117.5 mm x 35 mm and weighs 550 grams. The flight unit did not exceed that of the commercial unit by more than three centimeters in any dimension and by more than 500 grams in mass. Main power is supplied by alkaline "AA" size batteries which have a twenty-four hour usage life. The MSRR clock and memory back-up is powered by one silver oxide miniature battery. The recording medium is a C-120 cassette tape. Each tape can store up to twenty-four hours of recorded data. The recorder contains all of the signal conditioning circuitry, including the eight integral dual purpose input amplifiers, necessary to record EEG, EOG, and EMG.

### **Medical Experiment System (NASA,ESA,DARA)**

Various equipment are loaded to measure various physical data such as blood pressure, ECG and muscle sympathetic nerve activity onboard. These measurements are performed in response to the stressors such as the lower body negative pressure and handgrip loaded in Spacelab. These data will be processed by computer on board.

### **Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI): Slow Rotating Centrifuge Microscope**

The NIZEMI (Niedergeschwindigkeits-Zentrifugen-Mikroskop) is a Spacelab facility for optical investigations of small biological and non-biological specimens under variable accelerations from .001 to 1.5-g. It consists of a microscope for investigations in microgravity (no rotation) and under "selected" gravity (with rotation). The minimum and maximum gravity levels correspond to an effective radius of the samples of 110 mm and rotation speeds of 2.6 and 120 rpm, respectively. The equipment mounted on the NIZEMI centrifuge consists of a micro and a macro observation unit. The micro observation unit is a microscope using various contrast-enhancing methods and filters. Relevant functions such as object selection, magnification, and focusing adjustments are remotely controlled during centrifuge rotation. The object planes of the micro and macro units have a defined distance to the rotation axis of approximately 125 mm. Video displays can be downlinked in real-time or recorded. Normally the micro and macro observation units are not used concurrently. Individual micro and macro chambers can be customized within the standard interfaces. The prepared specimen, stored in a special micro chamber, can easily be positioned on the stage by a crew member. The facility is automatically controlled via dedicated processor electronics. Visual observation is possible via onboard monitoring, onboard video recording and optional video downlink or via in-situ photography. Cuvette temperature is automatically controlled between 18 and 37 degrees Celsius. Micro chambers with samples can also be stored onboard within a Biorack experiment container Type I (i.e., cooler, reference centrifuge, incubator or freezer).

### **Otolith Spinal Reflex / "Drop" Station**

#### **RELEASE MECHANISM: (T-Handle)**

The release handle is activated by command from the ECDS/ Microcomputer System (EMS) after being triggered by the crewmember operated cue switch.

#### **HARNESS AND BELT:**

A shoulder-type safety harness is used in combination with a wide, strong, tight-fitting adjustable belt. The EMG Amplifier secures to a velcro patch on the harness, and the Accelerometry Recording Unit (ARU) Power Pack and Cassette Data Tape Recorder (CDTR) are on a separate belt worn by the subject.

#### **FOOT SWITCH:**

The foot switch sole is attached to the bottom of the boot by double-sided adhesive rings. It signals contact of the crewman's foot with the floor of the Spacelab.

#### **BUNGEE CORDS:**

From three to nine Constant-Acceleration-Fall (CAF) bungees are used. During experiment operation they are attached to the floor and belt to simulate g-forces. Bungees not being used are held back with velcro straps.

#### **ELECTROMYOGRAM(EMG) AMPLIFIER AND ELECTRODE KIT:**

One LSLE amplifier/signal conditioner is used to monitor calf muscle activity. The amplifier is similar to those used with the dome although of much lower gain. Data is routed through the drop cable to the EMS. The EMG Electrode Kit is a ziplock bag and contains three pre-gelled disposable electrodes, one alcohol pad and one sterile needle for scratching the skin. The kit contains electrodes for one experiment run on one subject.

#### **Percutaneous Electrical Muscle Stimulator (PEMS)**

The Percutaneous Electrical Muscle Stimulator (PEMS) is a high voltage instrument which provides single pulses or pulse trains according to a preadjusted program. The pulses are square wave signals of 50 microseconds in duration and from 100 to 800 milliamperes (mA) intensity, thereby allowing the hardware to adjust the signal in 50 mA steps.

The PEMS is stowed during launch and landing. In orbit, the PEMS Main Box is unstowed and mounted to the rack handrail via a Multiuse Mounting Bracket Assembly. The connecting cables (power and the cables to the electrodes) have to be unstowed and connected with their ports on the back of the Main Box. The major electronic units of the Main Box are the power supply, the unit adapter, the interface module, and the high voltage stimulator. The power supply converts the 28 volts DC from the Space Shuttle's power source into 5, 12, and 15 volts DC as needed. The main task of the unit adapter (UA) is to generate the selected pre-programmed protocol and its trigger (muscle stimulation). The interface module is designed to select 8 different protocols and 16 different intensities of stimulation, with positions ranging from 100 to 800 mA. It also includes a Protocol Start and a Protocol Stop switch as well as an LED display, indicating the status of the PEMS. The High Voltage Stimulator (HVS) is the outlet of the triggers, and connects to the stimulating and safety electrodes positioned on the astronaut's leg.

The electrodes used for the PEMS have the characteristics of auto-adhesive, pre-gelled, and reusable electrodes. The cathode-electrode measures 3 x 5 inches and is positioned above the two heads of the gastrocnemius muscle (approximately 1 inch below the knee on the back of the leg). The anode-electrode is 1.5 x 3.5 inches in size and is positioned over the soleus muscle. The two safety electrodes are 2 inches in diameter and are positioned on the outside thigh, just above the knee.

#### **Performance Assessment Workstation (PAWS)**

The Performance Assessment Workstation (PAWS) was developed and validated for space flight to collect cognitive performance data and was first flown as part of the payload for the Second International Microgravity Laboratory (IML-2) on board the Space Shuttle Columbia (STS-65) in July of 1994. It consists of an IBM ThinkPad laptop computer, using the Microsoft Disk Operating System (DOS), with an active matrix color display and a NASA-compatible trackball. The computer used in flight was modified

by NASA to enhance its operation in the microgravity/Shuttle environment. These modifications did not affect its functionality. The PAWS requires a Measurement Systems, Inc. (MSI) 2-inch trackball (Model 622) connected to the serial port at 9600 baud and powered by 28 volts DC from the Shuttle power.

### **Physiological Monitoring System (PMS)**

The PMS provides EKG, heart rate and indirect blood pressure. In addition, the unit accepts the input from various data detection sources (e.g. the SVOP or SMCVP) and routes these data to the appropriate onboard data display, recording, transmission interface, or manipulation devices. Each data channel input to the PMS has the capability to be output to the body-worn LSLE cassette data tape recorder (CDTR), the Orbiter analog telemetry downlink interface or the LSLE microcomputer. The PMS is capable of being self-powered (battery operated) or spacecraft powered.

The main PMS module is subdivided into two major segments, the Basic Parameters Module (BPM) and the Data Control Module (DCM). The BPM contains all equipment and systems necessary to obtain ECG, heart rate, Korotkoff sounds (K-sounds), cuff pressure data, and conditions the same for interface into the DCM. The DCM controls and distributes the data from the BPM and interfaces this data into the various display, recording, transmission interfaces, or computation/manipulation devices. Certain preprogrammed computational and scaling processes can be performed on the input data by the PMS prior to data transmission.

The Remote Control Display Unit (RCDU) displays heart rate and blood pressure measurements through an umbilical from the PMS Electronics Module. The unit contains a liquid crystal display (LCD) capable of showing two lines of 32 characters of visual data of any type to the crewmembers. The controls of the unit may be used by the crewmember to control any preprogrammed operation, such as calibration or blood pressure measurements.

Note: Additional Experiment Unique Equipment (EUE) may be used in conjunction with this system. For example, the System for Venous Occlusion Plethysmography (SVOP) and System for Measurement of Central Venous Pressure (SMCVP), routed their signals through the PMS.

### **Physiological Signal Conditioner (PSC)**

The Physiological Signal Conditioner (PSC) is a compact, lightweight, low-power precision instrument designed to monitor physiological signals such as electromyogram (EMG) and electrocardiogram (ECG).

The PSC picks up physiological signals from surface electrodes, which are amplified and filtered. The analog output is received by an Electronics Control Assembly (ECA). The PSC is battery powered and uses 2 packs of five 1.5 volt silver oxide batteries. It can operate for more than 100 hours on a single set of batteries and the batteries can be easily changed during the space flight, without the need for tools. The operating status of the PSC is indicated by a small LED; a periodic blinking signal indicates nominal operations, while a fast blinking signal refers to low batteries. The battery power is applied and removed by connecting and disconnecting the output cable. The single-channel PSC, which was used for ECG recording, is approximately 6.2 x 4.7 x 3 centimeters and weighs no more than 300 grams with the batteries installed.

### **Plant Growth Unit (PGU)**

The Plant Growth Unit (PGU) is a self-contained system carried in the Orbiter middeck and designed to hold six removable Plant Growth Chambers. The PGU consists of the support components and a cavity for growing plants. The PGU is equipped with three 15 W plant growth lamps (Vita-Lite spectrum), a timer to provide day/night cycling, temperature sensors, electronically-controlled fans, heater strips for temperature modification, data-acquisition system, and internal batteries. The few system controls and displays appear on the exterior front panel. These include several status lights, a power switch, and a selectable digital temperature readout. Four switches that set the clock and a digital time display are located inside the unit. Temperatures and lamp status are recorded at intervals in flight by a tape recorder.

For environmental control, two thermostatically-controlled variable-speed fans draw air over the plant growth chambers. A temperature gradient decreasing from the top to the bottom of the chambers is maintained to prevent moisture condensation in front of the light. Diurnal temperature cycling is provided, with a chamber temperature of  $78 \pm 1$  °F during the "daylight" and  $74 \pm 1$  °F during the "night."

The PGU replaces a storage locker in the Orbiter middeck and can be placed into the Orbiter approximately twelve hours before launch and removed approximately one hour after landing.

**Plant Growth Chamber:** Each of the six chambers hold seeds or seedlings between sheets of moist filter paper-like material and consist of a metal alloy base and a Lexan cover which is sealed to the base using a gasket. Each chamber is airtight. The chamber base is fitted with a temperature probe in the center and two gas-sampling ports toward each end. Seeds or seedlings are planted in a "sandwich" support medium contained in the base. The chambers fit into the Plant Growth Unit which supplies all environmental control and power.

**Lighting System:** The lighting system consists of three fluorescent lamps containing phosphor lenses, reflector, aluminum housing, and associated circuitry. The filament and header designs are ruggedized; the lamp assembly is hermetically sealed with teflon tubing; and an indium-mercury amalgam is substituted for elemental mercury. The light intensity over the four middle plant growth chambers is about  $75 \mu\text{mol}/\text{m}^2/\text{sec}$  and over the two outside chambers about  $48 \mu\text{mol}/\text{m}^2/\text{sec}$ . Diurnal cycles are adjustable.

### **Rebreathing Assembly (RBA)**

The rebreathing assembly contains the valving and bag needed to perform rebreathing and other measurements.

Part of the Bag-In-Box Assembly (ALFE), the rebreathing assembly has two rotary valves designated left and right. The Left Handle controls the source of inspired gas. The Right Handle controls the expiration path. Other Support Hardware for this experiment include the Spirometry Assembly.

### **Refrigerator/Incubator Module (R/IM)**

The refrigerator/incubator module is an active unit with a temperature range from 4 to 40 degrees Celsius. It is flown in place of a standard middeck stowage locker or may be mounted to the Spacelab Middeck Experiment (SMIDEX) rack. Power consumption is 136 watts at 100 percent duty cycle and from 4 to 70 watts at a 70 percent duty cycle (empty). The temperature is set using a front-mounted variable potentiometer, with switching between the refrigeration and incubation modes occurring automatically. Front-mounted heat/cool LED indicators and a power switch are also provided.

**R/IM Design:** The R/IM uses a solid-state heat pump to maintain a cooled or heated internal environment. A fan circulates cabin air through the heat pump heat sink and is exhausted through ducts in the top and bottom surfaces of the unit's outer shell. Air is not circulated within the internal cavity. Stability of the temperature at the reference sensor is maintained within plus or minus 0.5 degrees Celsius of a set point within 20 degrees Celsius of ambient temperature. The unit uses 28 volts of power. A vent valve on the front door automatically controls internal pressure to within 0.5 psi of ambient pressure and can be manually activated to permit venting a negative pressure that may prevent opening of the R/IM door. To accommodate experiments, rail guides and fasteners are provided as a means of mounting up to six shelves of experiment hardware. The interior of the R/IM is composed of two cavities. The primary cavity, on the right, measures 6.46 x 10.19 x 14.56 inches or 958 cubic inches. The smaller cavity, on the left, is 60 cubic inches.

**R/IM Features:** The temperature desired is selected by a ten-turn precision potentiometer with a digital turn-counting indicator and locking device. The temperature controller has a time-proportioning output and integral action to bring the desired temperature to equal the set point. Two light-emitting diodes indicate the mode of operation (heat or cool) and the duty cycle of the heat pump. A digital display monitors the internal temperature of the unit. The temperature is derived from a Resistance Temperature Device (RTD) on the left rear wall of the cavity.

The original R/IM that was designed and built was flown on four shuttle flights prior to the extensive modifications that resulted in the version flown on SLS-1 and subsequent missions.

### **Rodent Research Animal Holding Facility (NASA)**

The RAHF is a general-use facility for housing rodents to be used in life science experiments aboard the Spacelab. The RAHF is installed in a double rack to provide environment control, food, illumination, and waste management for the animals on board. The data system in the RAHF is designed to interface with the Spacelab data acquisition systems. The RAHF houses twelve rodent cage assemblies. Each cage contains a waste management system, and individual feeders and watering Lixits. Control can be exercised for overall cage module temperature and day/night lighting for each of four cage module quadrants.

### **Saliva Collection Kit**

The saliva collection kit is a cloth (Nomex) pouch containing a foam insert designed to hold 14 salivettes in place. The salivette is a test tube system designed for standardized hygienic collection of mixed saliva in the mouth. Saliva is collected onto a cotton pledget that is placed in the vial.

### **System for Measurement of Central Venous Pressure (SMCVP)**

The SMCVP provides a means for measuring central venous pressure continuously while ambulatory.

The apparatus consists of three parts, the electronics module, the pump chamber and the transducer block. The transducer block is mounted in the armpit at the level of the right atrium. Pressure is transmitted to the transducer through a 4 French polyurethane catheter inserted through an arm vein. Electrical isolation from the transducer face is provided by two latex diaphragms and a non-conductive fluid covering the transducer (Dow Corning 360 medical fluid). The pump chamber provides a slow, continuous infusion of heparinized saline at 1.5 ml/hour. The electronics box contains the circuitry to amplify the transducer output and send it to the PMS for recording or downlink. The signal is recorded on the Cassette Data Tape Recorder. The SMCVP provides an analog output signal of 0-5 volts DC corresponding to a catheter pressure of -10 to 40 mmHg. This signal may be downlinked for monitoring experiment operations.

### **System for Venous Occlusion Plethysmography (SVOP)**

**CONCEPT:** This item detects changes in the circumference of the arm or calf in response to venous occlusion, using the venous occlusion plethysmography technique.

**DESCRIPTION:** Occlusion of venous flow is accomplished by step increases in pressure in a cuff above the elbow or thigh. For a flow measurement, an occlusion pressure of 60 mmHg was used. For compliance measurements, pressure was increased as follows: 20 mmHg for one minute, then one minute at 0 mmHg, 40 mmHg for 2 minutes, one minute at 0 mmHg, 3 minutes at 60 mmHg, one minute at 0 mmHg, then 80 mmHg for 4 minutes. The SVOP system has the capability to accurately measure changes in limb circumference as small as .0199 mm. An analog signal (0 to +5VDC) from the SVOP is transmitted to the NASA-provided Physiological Monitoring System (PMS) for recording and downlink. On the ground the signal is recorded on a strip chart recorder and analog recorder. Equilibrated calf volumes are calculated using limb circumference values to provide a measure of venous compliance. An accessory to the SVOP is a NASA-provided blood pressure cuff with a bulb and gauge (0-300 mmHg) for occluding arterial circulation to the foot.

### **Temperature Recorder: Ambient (ATR-4)**

The Ambient Temperature Recorder (ATR-4) is a self-contained, battery-powered package that may be placed in almost any environment to provide continuous recording of up to four channels of temperature data. Channel 1 features both an internal and external sensing capability. In the "internal" position, Channel 1 senses temperature through a temperature sensor that is thermally bonded to the ATR-4 case. In the "external" position, Channel 1 uses an externally connected temperature probe to sense temperature.



Channels 2-4 are "external only" and require individual external temperature probes. External temperature probes are flexible in design to allow the user to place probes at various different locations within the sensed environment. Standard length for the external probes is 3 feet.

The ATR-4 periodically senses and stores in its solid state memory up to four channels of temperature data. Stored data may be read out postflight using a serial interface unit and an IBM-compatible computer. Both sample rate and number of channels are user-selectable, the total number of samples being limited by the size of the internal memory. When the memory is full, the recorder stops recording. Power for the ATR-4 is provided by two internal lithium batteries. The case is fabricated of aluminum and is approximately the size of a deck of cards. A special O-ring seal functions both to protect the ATR-4's internal electronics from fluids in the environment, and to permit operation of the ATR-4 in damp or humid environments such as an animal habitat.

The Shuttle-qualified ATR-4 has a temperature range of -40 degrees C to +60 degrees C with an accuracy of  $\pm 1^\circ\text{C}$ . Four sample rates are available, including 1-4 samples per 1.87, 3.75, 7.5 or 15 minutes. Depending on the sample rate selected and total number of channels in use, various recording durations are possible. Examples at the limits are:

1 channel: 1 sample/ 1.87 minutes = 42 days  
1 channel: 1 sample/ 15 minutes = 342 days  
4 channels: 4 samples/ 1.87 minutes = 10 days  
4 channels: 4 samples/ 15 minutes = 85 days

### **Torso Rotation Experiment (TRE)**

The Torso Rotation Experiment (TRE) head-mounted unit contains a 3-axis Watson angular velocity transducer, an electro-oculogram (EOG) preamplifier, an isolation amplifier for electroshock protection, and temperature sensors to monitor transducer temperature. The head unit is worn on top of the subject's head and secured with the Head Interface consisting of a strap assembly placed over the top of the skull, under the chin and around the back of the head. The unit including cables measures 12.7 x 7.6 x 7.6 cm and weighs 2.43 kg. The unit will be firmly attached to the head by means of a head-band interface. Two cable sets are fixed to the head unit, one coming from three surface electrodes used to record the eye movements and one going to the back-mounted package. The head unit is connected to the torso unit by means of a flexible shielded cable to transfer data for storage. One Electrode Kit is flown containing 40 disposable surface monitoring electrodes, 40 alcohol wipes and one metal mirror to aid in electrode placement.

The interface to the head unit consists of an adapter that includes flexible metal straps running across the top and back of the head and an adjustable chin strap of Nomex webbing and velcro. The relative angles of the straps are fixed by locking knobs on the sides of the head. The head interface measures 20.3 x 15.2 x 3.8 cm and weighs 0.66 kg.

The Torso Rotation Experiment (TRE) torso- or back-mounted unit contains a 3-axis Watson transducer, a temperature sensor, a calendar clock, an auto-resetting electro-oculogram (EOG) amplifier, other signal conditioning amplifiers, anti-aliasing filters, a 12-bit A/D converter, and a Motorola 68000 series microprocessor. It also has a single LED and a beeper to provide certain information to the operator. This unit contains the majority of the electronics used in the TRE experiment. The power supply for all the electronics is located in the back-mounted unit, and consists of eight 9-volt batteries, three for +15 and +12 volt, three for -15 volt, and two for +5 volt. All are regulated down to the desired voltages and have sufficient capacity to complete 8 full experiment runs without being changed. The power supply is fused at the batteries. All electronic circuits use CMOS technology and all are floated from their machined aluminum cases. The unit is gold plated over nickel, inside and out.

The interface to the torso is a modification of a device used to immobilize the head and neck of accident victims. In this case, only the chest and back plates are used, connected together by two straps over the shoulders and two others around the sides of the chest (under the arms). It is somewhat difficult to fix equipment onto the upper back in a secure fashion but this method has been shown to work when a subject

is upside down in a 1-g environment. The torso interface measures 35.6 x 25.4 x 5.1 cm and weighs 2.21 kg.

### **Torque Velocity Dynamometer (TVD)**

The complementary nature of the musculoskeletal experiments flown on board the Life and Microgravity Science Laboratory (LMS) engendered the development of the multi-purpose Torque Velocity Dynamometer (TVD). The TVD was developed by the European Space Agency (ESA) specifically in response to the science requirement of the LMS mission.

The TVD measures torque, which is the turning effect produced when force is applied to a rotational axis. For TVD measurements, contracting muscles associated with elbow and ankle joints apply force against a lever arm attached to a shaft on the dynamometer's motor (the rotational element). A sensor in the TVD measures the resulting torque. Because the muscles produce force both as they contract to move the arm or foot and also as they resist being moved by external influences, the TVD provides a measurement of torque under both conditions: (1) as the subject voluntarily moves the elbow or ankle to rotate the dynamometer's motor and (2) as the subject actively resists having the elbow or ankle moved by the lever arm as it was driven by the motor. In addition to torque measurements, the TVD gauges the rate at which an arm or foot moves through its range of motion (the angular velocity of the elbow or ankle). These types of mechanical measurements enable scientists to calculate levels of muscle performance and function, including strength, energy expenditure, and fatigue.

The main unit of the dynamometer is located on the floor of the Spacelab center aisle. Inside are the torque sensor, motor, gears, and electronics that drive the device. Special knee, foot, and arm restraints, called Human Interfaces (HIFs), mechanically connect the subject to the TVD. A movable plate attached to the outside of the main unit positions and fixes the HIFs to restrain any limb movement that may compromise the experiments. The leg HIFs have knee and shin restraints, while the arm HIFs prevent wrist rotation and upper forearm movement. Another restraint prevents the shoulder from reacting to the torque produced by a flexing elbow. The subject support plate, a cushioned platform outfitted with shoulder and waist belts to restrain the torso, can be positioned so that it allows the test subject to perform the experiments in comfort and without unnecessary movement.

The TVD can hold an arm or foot in a stationary position with the elbow or ankle at a fixed angle for isometric exercises (the subject contracts the muscles without moving the lever arm of the TVD). The TVD can also move the arm or leg to alter the angle of the elbow or ankle so that the attached muscles change length at a constant speed (isokinetic measurements), thereby the changing rate is programmable by the TVD. In addition, the TVD supports isotonic measurements while the muscles are either shortening (concentric movement) or lengthening (eccentric movement). In the isotonic experiments, the muscle either moves against or is moved by a specific load of resistance applied by the TVD. During concentric movement, the TVD measures torque as the arm or leg muscles actively contract (shorten) against a known resistance, decreasing the joint angle. During eccentric movement, the device records the torque generated as the TVD causes the joint angle to increase while the test subject actively contracts the limb muscles, resisting the movement.

To perform the musculoskeletal experiments, the subject lays on the support plate, with torso and limbs secured to the appropriate HIF. Following instructions displayed on the TVD control/display panel, the subject then performs a safety check of the dynamometer. After the safety test is completed, the subject uses either the TVD control/display panel or an external microcomputer to begin the experiment run. The microcomputer captures and displays the resulting measurements.

### **Urine Monitoring System (UMS)**

The UMS supports metabolic experiments by preparing urine samples for return to ground for postflight analysis. It automatically collects, measures, and samples individual micturitions in either zero gravity or normal gravity environment and accommodates both male and female users.

The UMS includes a mechanical assembly connected to an electronic control assembly with a urine collection hose and a urine discharge hose. It also includes a flush water hose and microbial check valve. Water for flush is obtained by connection to the Shuttle Cross-Tie QD. The UMS urine discharge hose is connected to the Shuttle Waste Collection System Urine inlet port during inflight operations and the UMS itself is attached to the middeck hatch by velcro and a strap assembly.

The UMS operates off of 28 volts DC Shuttle Power and is protected by a 5 amp fuse. The operation of the UMS is semiautomatic. A microprocessor is used to provide for software controlled automatic functions. Components that include moving parts are the phase separator, the urine pump, the flush water solenoid valves and the urine discharge solenoid valve. The rotation of the phase separator is required to produce the centrifugal forces to separate the liquid from the air. The urine pump is used to pump the urine from the separator through a line which runs parallel to the air discharge hose and then connects near the end of the air discharge hose just before it enters into the waste collection system inlet port. The flush water solenoid valves (normally closed) are used to introduce flush water into the system to flush out the interior surfaces of the UMS hoses and separator before being pumped out through the urine discharge line. The urine discharge solenoid valve is used to control the out flow of urine from the UMS to the Waste Collection System (WCS) when the urine pump is running and is opened during the urine pump out and closed during sample collection.

During in-orbit operations, the UMS is installed in the middeck hatch and is stowed in a middeck locker during launch and landing

Samples can be preserved with chemicals or by freezing. The UMS interfaces with Orbiter Waste Collection System (WCS).

### **Venous Occlusion Cuff Controller (VOCC)**

The venous occlusion cuff is used to incrementally occlude venous outflow of the measured limb for making flow and compliance measurements using venous occlusion plethysmography.

The unit consists of a pump, electronic controls and a cuff. The electronics control inflation, deflation, and the rate of inflation, deflation. The source of power for the unit is a battery powered air pump.

This device inflates the occlusion cuff around the thigh. The mode button cycles the device through three modes. Mode 1 is flow mode. Mode 2 is compliance mode, which inflates the cuff to pressure levels stated in the compliance protocol (20 mmHg - 40 mmHg - 60 mmHg - 80 mmHg - 100 mmHg). Mode 3 is the programming mode wherein the flow and compliance pressures can be changed.

Safety features included:

1. Manual start and abort
2. Automatic abort above 300 mmHg, fixed time interval
3. Warning before start of cycle
4. Deflation of cuff during power loss

### **Vestibular Function Experiment Unit (VFEU) (NASDA) Neural Data Acquisition System (NDAS) (NASDA)**

The Vestibular Function Experiment Unit (VFEU) and Neural Data Acquisition System (NDAS) are provided by NASDA for Neurolab and developed based on the VFEU which was flown in Spacelab-J (SL-J) and the Aquatic Animal Experiment Unit (AAEU) which was further improved in the life support capability assessed in International Microgravity Laboratory-2 (IML-2).

The functions of VFEU and NDAS are to maintain long-term animal life support, record experiment data of neural activities and acceleration continuously over the mission duration as well as downlink to the ground. The VFEU is used for the microgravity experiment of sea animal. The function of VFEU is to maintain long-term animal life support and support the neural experiment. The functions of NDAS are to

measure, transmit, process and record the experiment data of neural activities and acceleration continuously over the mission duration as well as downlink to the ground. The power supply to transmitter is without wire. This equipment is to measure the experiment data without animal restraint. The main components of NDAS are the Data Interface Unit, the Data Interface Unit, the Data Recorder, the Receiver, the Transmitter, and the Inductive Coil.

### **Visual Vestibular Investigation System (VVIS) (ESA)**

The VVIS consists of the Body Rotating Device (BRD), Eye Stimulation & Movement Recording System (ESMRS) and Experiment Control System (ECS). The BRD is primarily a seat driven by a motor located in the Spacelab, which is to rotate the test subject, and generates the acceleration. The ESMRS is attached to the top of the BRD and in front of the subject head. This hardware has the darkness curtain, eye stimulation system and eye recording cameras in it, for stimulation and recording of eye movement.

## Appendix C:

### Publications Resulting from Spacelab Life Sciences Experiments\*

\*Entries may be followed by two sets of brackets. The first indicates the Mission from which the publication data was obtained; the second gives the totals per year and to-date of all citations referencing the publication.

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**Appendix D:**  
**Some Internet Websites with Spacelab Mission Information**

Sponsoring Agency	Web Address	Spacelab Missions Archived
Johnson Space Center: NASA Life Sciences Data Archive	<a href="http://lsda.jsc.nasa.gov/">http://lsda.jsc.nasa.gov/</a>	Spacelab 1 (STS-9) Spacelab 2 (STS-51F) Spacelab 3 (STS-51B) Spacelab D-1 (STS-61A) Spacelab Life Sciences 1 (STS-40) International Microgravity Laboratory 1 (STS-42) Spacelab J (STS-47) Spacelab Life Sciences 2 (STS-58) Spacelab D-2 (STS-55) International Microgravity Laboratory 2 (STS-65) Life and Microgravity Spacelab (STS-78) Neurolab (STS-90) Spacelab-Mir (STS-71) OSTA-1 (STS-2) OSS-1 (STS-3)
European Space Agency, ESA Microgravity Database (Life Sciences)	<a href="http://www.esrin.esa.it/mgdb/mgdbhome.html">http://www.esrin.esa.it/mgdb/mgdbhome.html</a>	Spacelab 1 (STS-9) Spacelab D-1 (STS-61A) Spacelab Life Sciences 1 (STS-40) International Microgravity Laboratory 1 (STS-42) Spacelab Life Sciences 2 (STS-58) Spacelab D-2 (STS-55) International Microgravity Laboratory 2 (STS-65) Life and Microgravity Spacelab (STS-78)
National Space Development Agency of Japan, NASDA	<a href="http://www.nasda.go.jp/index_e.html">http://www.nasda.go.jp/index_e.html</a>	Spacelab J (STS-47) Neurolab (STS-90)
Spacelink: NASA STS-73/USML-2 Information	<a href="http://spacelink.nasa.gov/NASA.Projects/Human.Exploration.and.Development.of.Space/Human.Space.Flight/Shuttle/Shuttle.Missions/Flight.072.STS-73/USML-2.Mission.Experiments/.index.html">http://spacelink.nasa.gov/NASA.Projects/Human.Exploration.and.Development.of.Space/Human.Space.Flight/Shuttle/Shuttle.Missions/Flight.072.STS-73/USML-2.Mission.Experiments/.index.html</a>	United States Microgravity Laboratory 2 (STS-73)
NASA's Neurolab Homepage	<a href="http://www.neurolab.nasa.gov/">http://www.neurolab.nasa.gov/</a>	Neurolab (STS-90)
Shuttle-Mir Homepage	<a href="http://spaceflight.nasa.gov/history/shuttle-mir/science/shuttmir/shitmir/res.htm">http://spaceflight.nasa.gov/history/shuttle-mir/science/shuttmir/shitmir/res.htm</a>	Spacelab-Mir (STS-71)



## Appendix E.

### TECHNOLOGY SPIN-OFFS

## TECHNOLOGY SPIN-OFFS

In general, the life sciences experiments described in this document were not designed as technology development but rather as research to gain understanding influence of gravity (microgravity) and spaceflight on living organisms or factors affecting human welfare, habitation and exploration of space. For this reason, only three technologies with commercial potential are mentioned as technology spin-offs from the life sciences Spacelab missions. Two of these are plant growth support facilities. The third is a gravity/acceleration sensing device. Descriptions of the plant facilities can be found in the text of Section II, "Significant Scientific Result Summaries" and will not be repeated here.

1. Astroculture™ (page 30, Section II)
2. The "Svet" Facility (page 32, Section II)
3. The 3-Dimensional Microgravity Accelerometer (3-DMA) described below.

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### The 3-Dimensional Microgravity Accelerometer (3-DMA)

The 3-DMA was developed by the University of Alabama in Huntsville Consortium for Materials Development in Space. Acceleration is measured at four locations in three orthogonal axes, all data is automatically recorded on board for the full mission duration. At each of the four measurement locations and each of the three axes, acceleration measurement channels provide three signal frequency bands simultaneously and continuously. These are 0-1 Hz, 0-10 Hz, and 0-300 Hz. These are chosen to enable increasing measurement sensitivities according to space station requirements in the ranges of the spectrum of disturbances normally occurring on orbiting platforms. The noise level in the fine channel is derived from manufacturer's measured data and is 0.07ug. The 3-DMA has flown on five Shuttle missions, including Spacelab USML. The 3-DMA units flown on the Shuttle have three remote sensing units for measuring microvibrations and a central unit that houses the processing and recording hardware and invertable accelerometers for measuring quasi-stationary components.

Recent publications of ground based research using vibration tables to simulate Shuttle launch vibrations have divulged that cultured cells and cells in suspension are sensitive to vibration. If the responses of living systems to altered gravity is to be understood, it is necessary to consider the effects of the environmental variables. Vibration and acceleration are components of spaceflight just as is microgravity and cosmic radiation, therefore it is critical to separate the effects of these environmental perturbations from "microgravity" effects if we are to understand gravitational effects on living systems. On USML-2, the 3-DMA detected very significant vibratory disturbances of 12.5 and 19 Hz. These were found to be disturbances from the Glove Box fans. The "g-jitter" resulting from strong transient pulses from burns of Shuttle Primary Reaction Control System were in the milli-g range (1000 micro-g's) and were easily found on the plots of the 3-DMA data. The threshold values for vibrational effects at the cellular level are not known. We are beginning to understand the threshold for gravity effects on plants and

other organisms. With the 3-DMA, it is possible to determine the g-levels in the vicinity of individual experiments. The 3-DMA has applicability to life sciences investigations as well as for commercial applications on the ground. (Bijvoet, J.A. and Nerren P.D. The need for low-cost microgravity environment characterization for materials development in space. IAF-97-J.2.01)



## Fluids And Combustion Experiments by Mission

### Capillarity Effects

Haynes, J.M	Kinetics of Spreading of Liquids in Microgravity	SL-1	11/28/83
Padday, J. F	Capillary Forces	SL-1	11/28/83
Pan, C.H.T.	Tribology Experiments in Zero Gravity	SL-1	11/28/83
Vreeburg, J. P. B	Axisymmetric Free Surface Behaviour of Moving Liquid in a Cylinder	SL-1	11/28/83
Vreeburg, J.P.B	Liquid Motions In Partially Filled Containers	D-1	10/30/85
Concus, P. ,Finn, R.; Weislogel, M. M.	Interface Configuration Experiment (ICE)	USML-1	6/25/92
Langbein, D.; Weislogel, M.;	Dynamics of Liquids in Edges and Corners	IML-2	7/8/94
Concus, P.; Finn, R.;			
Concus, Paul	Interface Configuration Experiment	USML-2	10/20/95

### Zone Shape and Stability

Martinez, I.; Da Riva, I.; Meseguer, J.; Sanz, A.;	Floating Zone Stability in Zero Gravity	SL-1	11/28/83
Martinez, I.; Da Riva, I.; Meseguer, J.; Sanz, A	Floating Zone Hydrodynamics.	D-1	10/30/85
Padday, J. F	Capillarity. Adhesion Forces in Liquid Films	D-1	10/30/85
Naumann, R.J., Langbein, D., Ramachandran, N	Stability of a Double Float Zone (DFZ)	USML-1	6/25/92
Naumann, R.J., Dunbar, B.J. Nover, D.	Fiber Pulling in Microgravity	USML-1	6/25/92
Langbein, D.	Liquid columns Resonance	D-2	4/26/93
Martinez, I., Perales, J. M., Meseguer, J.	Stability of Long Columns	D-2	4/26/93
Saville, D.	The Electrohydrodynamics of Liquid Bridges	LMS	6/20/96

### Marangoni Convection

Napolitano, L. G.; Monti, R.;	Free Convection in Low Gravity	SL-1	11/28/83
Drinkenburg, A.A.H.; Lichtenbelt, J. H.; Dijkstra, H. A	Marangoni Convection in Relation to Mass Transfer from the Liquid to the Gas Phase: MACO A and MACO B	D-1	10/30/85
Legros, J.C.; Limbourg-Fontaine, M.C.; Petre, G	Surface Tension Induced Convection around a Surface Tension Minimum	D-1	10/30/85
Napolitano, L.G.; Monti, R.; Russo, G.	Marangoni Flows	D-1	10/30/85
Schwabe, D.; Lamprecht, R.;	Marangoni Convection in an Open Boat	D-1	10/30/85
Scharmann, A.			
Naumann, R.J.	Marangoni Convection in Closed Containers	USML-1	6/25/92
Ostrach, S., Kamotani, Y., Pline, A.	Oscillatory Thermocapillary Flow Experiment	USML-1	6/25/92
Azuma, Hisao	Bubble Behavior in Temperature Gradient and Acoustic Wave Field, M-16	SL-J	9/12/92
Enya, S.	Marangoni Induced Convection in Materials Processing under Microgravity (M-18);	SL-J	9/12/92
Chun, Ch.-H., Siekmann, J.	Higher Modes and their Instabilities in Marangoni Convection	D-2	4/26/93
Cramer, A.Schwabe, D., J. Metzger, Scharmann, A.	Marangoni Convection in a Rectangular Cavity	D-2	4/26/93

Dupont, O., Queeckers, P.	Marangoni-Benard Instability	D-2	4/26/93
Monti, R.,	ONSET Experiment on D-2	D-2	4/26/93
Koster, J. N.	Interfacial Phenomena in a Multilayered Fluid System	IML-2	7/8/94
Kamotani, Yasuhiro	Oscillatory Thermocapillary Flow Experiment	USML-2	10/20/95
Ostrach, S., Kamotani, Y., Pline.A.	Surface Tension Driven Convection Experiment	USML-2	10/20/95
Legros, J., Géoris, P., Roux, B., Velarde, M,	Oscillatory Marangoni Instability	LMS	6/20/96

### Drop and Bubble Migration

Naehle, R., Neuhaus, D., Siekman, J.	Bubble Motions Induced by Temperature Gradient	D-1	10/30/85
Bewersdorff, A.;	Bubble Transport by Chemical Waves	D-1	10/30/85
Straub, J	Nucleation, bubble growth, interfacial phenomena, evaporation and condensation kinetics	IML-2	7/8/94
Monti, R. Fortezza, R	Bubbles and Drops Interaction with Solidification Fronts	LMS	6/20/96
Subramanian, R.S., R.	Thermocapillary Migration and Interactions of Bubbles and	LMS	6/20/96
Balasubramaniam, Günter Wozniak	Drops		
Viviani, Antonio	Nonlinear Surface Tension Driven Bubble Migration	LMS	6/20/96

### Heat Transfer in Microgravity

Straub, J.;	Boiling on a Miniature Heater under Microgravity: a Simulation for Cooling of Electronic Devices	IML-2	7/8/94
Straub, J.; Merte, H.	Efficient Cooling of High Powered Small Electronic Devices by Boiling Under Microgravity	LMS	6/20/96
Halliman, Kevin P.	Capillary-driven Heat Transfer	MSL-1R	7/1/97

### Critical Point Phenomena

Klein, H.; Wanders, K.	Density Distribution And Phase Separation In Fluids At The Critical Point	D-1	10/30/85
Straub, J.; Nitsche, K.	Heat Capacity near the Critical Point	D-1	10/30/85
Beysens, D.	Heat and Mass Transport in a Pure Fluid in the Vicinity of a Critical Point	IML-1	1/22/92
Michels, A. C.	Study of Density Distribution in a Near-Critical Simple Fluid	IML-1	1/22/92
Lipa, John A. , Chui, Talso C.P.	Lambda Point Experiment	USMP-1	10/22/92
Straub, J.; Haupt, A.	Fast Isentropic Temperature Propagation near the Critical Point	D-2	4/26/93
Straub, J.; Haupt, A.	Hysteresis of the specific isochoric heat during heating and cooling through the critical point	D-2	4/26/93
Ferrell, R. A	Thermal Equilibration in a One-Component Fluid	IML-2	7/8/94
Klein, H.; Ikier, C., Woermann, D.;	Density Equilibration Time Scale	IML-2	7/8/94
Gammon, Robert;	Critical Fluid Light Scattering Experiment (Zeno)	USMP-3	2/22/96
Lipa, John	Confined Helium Experiment	USMP-4	11/19/97

### Drop Dynamics

Rodot, H.; Bisch, C.;	Oscillation Of Semi-Free Liquid Spheres In Space	SL-1	11/28/83
Wang, T. G	Dynamics of Rotating and Oscillating Free Drops	SL-3	4/29/85

Subramanian, R.S.	Three-Axis Acoustic Levitator	MSL-2	1/12/86
Wang, Taylor	Three-Axis Acoustic Levitator	MSL-2	1/12/86
Apfel, R.E ,Elleman, D.; Holt, R. G.	Fluid Physics	USML-1	6/25/92
Marston, P.L., Trinh, E.H.; Depew, J.	Oscillatory Dynamics of Single Bubbles and Agglomeration in an Ultrasonic Sound Field in Microgravity	USML-1	6/25/92
Trinh, E. H., Depew, J.	Solid Surface Wetting Experiment	USML-1	6/25/92
Wang, T. ,Barmatz, M.; Anilkumar, A. V.; Lin, K. ; Trinh, E. H	Drop Dynamics Experiment	USML-1	6/25/92
Weinberg, M. C., Neilson, G. F. (2); Subramanian, R. S. (3); Trinh, E. H.	Phase Separation Kinetics of Fluid Glass Melts	USML-1	6/25/92
Yamanaka, Tatsuo	Drop Dynamics in Space and Interference with Acoustic Field, M-15	SL-J	9/12/92
Apfel, Robert	Science Technology of Surface Controlled Phenomena	USML-2	10/20/95
Wang, Taylor	Drops Dynamics Experiment	USML-2	10/20/95
Leal, L.G.	Bubble, Drop, and Non-Linear Dynamics	MSL-1R	7/1/97
Sadhil, S.S.	Internal Flows in a Free Drop	MSL-1R	7/1/97
<b>Miscellaneous Experiments</b>			
<b>Superfluid Helium</b>			
Mason, P. V	Superfluid Helium Experiment	SL-2	6/29/85
<b>Geophysical Fluid Flow</b>			
Hart, J. E.	Geophysical Fluid Flow Cell	SL-3	4/29/85
Hart, John	Geophysical Fluid Flow Cell Experiment	USML-2	10/20/95
<b>Order-Disorder Transitions</b>			
Chaikin, P. M.	Order -Disorder Transitions	USML-2	10/20/95
Chaikin, P. M.	Physics of Hard Spheres Experiment	MSL-1R	7/1/97
Russel, William	Dendritic Growth of Hard Spheres	USML-2	
<b>Particle Dispersion Experiment</b>			
Marshall, J.	Particle Dispersion Experiment	USML-1	6/25/92
Marshall, J.	Particle Dispersion Experiment	USML-2	10/20/95
<b>Passive Accelerometer</b>			
Alexander, J.I.D.	Passive Accelerometer	USML-1	6/25/92
<b>Mixing and Demixing</b>			
Langbein, D.	Mixing And Demixing Of Transparent Liquids.	D-1	10/30/85
<b>Combustion Experiments</b>			
Altenkirch, R. A.	Solid Surface Combustion Experiment (SSCE)	SLS-1	6/5/91
Altenkirch, R. A.	Solid Surface Combustion Experiment (SSCE)	IML-1	1/22/92
Altenkirch, R. A.	Solid Surface Combustion Experiment (SSCE)	USML-1	6/25/92
Greenberg, P. S., Kashiwagi, T.	Wire Insulation Flammability Experiment	USML-1	6/25/92

Olson, S. L.; Stocker, D. P., Fernandez-Pello, A. Carlos	Smoldering Combustion in Microgravity	USML-1	6/25/92
Ross, H.D., Dietrich, D.L., Tien, J.S.	Candle Flames in Microgravity	USML-1	6/25/92
Altenkirch, R. A.	Solid Surface Combustion Experiment (SSCE)	SL-J	9/12/92
Williams, Forman A.	Fiber Supported Droplet Combustion	USML-2	10/20/95
Urban, Griffin & Gard	Comparative Soot Diagnostics	USMP-3	2/22/96
Kashiwagi, Takashi	Radiative Ignition and Transition to Spread Investigation	USMP-3	2/22/96
Sacksteder, Kurt, R.	Forced-Flow Flamespreading Test	USMP-3	2/22/96
Faeth, Gerard	Laminar Soot Processes Facility	MSL-1R	7/1/97
Ronney, Paul	Structure of Flame Balls at Low Lewis-number	MSL-1R	7/1/97
Williams, Forman	Droplet Combustion Experiment	MSL-1R	7/1/97
Chen, Lea-Der, Stocker, D.	Enclosed Laminar Flames	USMP-4	11/19/97



## Materials Science Experiments

### Metals, Alloys, and Composites

<b>Eutectic Experiments</b>			11/28/83
Favier, J.J.; De Goer, J.;	Directional Solidification Of Eutectic Alloys.	SL-1	11/28/83
Mueller, G.; Kyr, P	Unidirectional Solidification Of Eutectics (InSb-NiSb).	SL-1	10/30/85
Mueller, G.; Kyr, P.	Directional Solidification of Indium-Antimonide Nickel-Antimonide Eutectic. Determination of Gravity Induced Convection on Fiber Spacing	D-1	1/12/86
Larson, David J.	Directional Solidification of Magnetically Aligned CoSm Composites (	MSL-2	9/12/92
Ohno, Atsumi	Solidification of Eutectic System Alloys in Space, M-19	SL-J	4/26/93
Tensi, H. M. , Roesch, R.	Thermoconvection at Dendritic-Eutectic Solidification of an AlSi11 Alloy	D-2	4/26/93
Wallrafen, F.; Dupré, K.	Directional Solidification of the LiF-LiBaF3 Eutectic	D-2	
 <b>Interfacial Stability</b>			
Carlberg, T	Morphological Stability with Different Convecton	SL-J	10/28/82
Billia, B; Favier, J.J;	Cellular Morphologies In Lead Thallium Alloys	D-1	10/30/85
Jamgotchian, H; Camel, D			
Potard, C.; Duffar, T.;	Growth Rate Measurement of Doped Indium-Antimonide Crystal	D-1	10/22/92
Dusserre, P.	by a Calorimetic Method under ...		
Favier,, Jean Jacques,	MEPHISTO-1	USMP-1	4/26/93
Rouzaud, Andre, Comera,			
Jean			
Nguyen Thi, H.; LI, Q.; Billia,	Cellular and Dendritic Solidification of Aluminium – Lithium	D-2	3/4/94
B.; Camel, D.; Drevet, B.;	Alloys		
Favier, J.J.			
Abbaschian, R.;	In Situ Monitoring of Crystal Growth using MEPHISTO	USMP-2	2/22/96
Favier, J. J.	MEPHISTO	USMP-3	6/20/96
Nguyen Thi, Henri	Comparative Study of Cells and Dendrites During Directional Solidification of a Binary Aluminum Alloy at 1-g and Under Microgravity	LMS	11/19/97
Abbaschian, Reza, Allen, D.	MEPHISTO	USMP-4	
 <b>Dendrite Studies</b>			
Camel, D.; Favier, J.J.	Dendritic Solidification Of Al-Cu Alloys	D-1	10/30/85
Mary H. McCay,	CAST	IML-1	1/22/92
Glicksman, Martin	Isothermal Dendritic Growth Experiment (IDGE)	USMP-2	3/4/94
Sato, A.	Effect of Weightlessness on Microstructure and Strength of Ordered TiAl Intermetallic Alloys	IML-2	7/8/94
Glicksman, Martin;	Isothermal Dendritic Growth Experiment (IDGE)	USMP-3	2/22/96
Dupouy, Camel	Directional Solidification of Refined Al-4wt%Cu Alloys	LMS	6/20/96
Herlach, D.M.	Morphological Stability of Growing by Comparative Dendrite Velocity	MSL-1R	7/1/97
Glicksman, Martin	Isothermal Dendritic Growth Experiment	USMP-4	11/19/97

### Coarsening and Ripening

Kneissl, A., Fischmeister Ratke, L., Theieringer, W.K., and Fischmeister, H. Voorhees, Peter	Particle Coarsening in Immiscible Zn-Pb Alloys Ostwald Ripening  Coarsening in Solid-Liquid Mixtures	 D-1  MSL-1R	10/30/85 7/1/97
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### Liquid Phase Sintering

Kohara, S. German, R. M. German, Randall	Study on the Mechanisms of Liquid Phase Sintering (M-12); Gravitational Role in Liquid Phase Sintering Liquid Phase Sintering II	SL-J IML-2 MSL-1R	9/12/92 7/8/94 7/1/97
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### Thermosolutal Convection

Rex, S.; Sahm, P.R. Stehle, M., Rex, S. Leonartz, K.	Planar Front Solidification of Aluminium-Magnesium Alloys Directional Solidification of a Cu-Mn Alloy Convective Stability of Solidification Fronts	D-1 D-2 IML-2	10/30/85 4/26/93 7/8/94
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### Monotectic Systems

Gelles, S. H. Otto, Guenther H. Ahlborn, H.(1); Lohberg, K Caton, P. D. Ahlborn, H.; Loehberg, K. Ecker, A.; Sahm, P. R.	Liquid Phase Miscibility Gap Materials Stability of Metallic Dispersions Influences Affecting Separation In Monotectic Alloys Under Metallic Emulsions Al-Pb Separation of Immiscible Melts GETS - Boundary Layers in Solidifying Transparent Melts: Holographic Observation of Solidification Processes	OSTA-2 OSTA-2 SL-1 SL-1 D-1 D-1	6/18/83 6/18/83 11/28/83 11/28/83 10/30/85 10/30/85 10/30/85
Gelles, S. H., Alan J. Markworth Kamio, Akihiko Togano, Kazumasa Braun, B.; Ikier, Ch.; Klein, H.; Schmitz, G.; Wanders, K, Woermann, D. Ratke, L., Prinz, B., Ahlborn, H. Sangiorgi, R.; Muolo, M.L.; Rossitto, F (2); Passerone, A. Andrews, Barry Andrews, Barry	Liquid Phase Miscibility Gap Materials  Study of Solidification of Immiscible Alloy, M-10 Casting of Superconducting Composite Materials Phase Separation in Liquid Mixtures with Miscibility Gap on D- 2  Separation Behavior of Monotectic Alloys  Interfacial tension and heterogeneous nucleation in immiscible liquid metal system Coupled Growth in Hypermonotectics Wetting Characteristics of Immiscibles	D-1  SL-J SL-J D-2  D-2  D-2  LMS USMP-4	9/12/92  9/12/92 4/26/93 4/26/93  4/26/93  6/20/96 11/19/97

### Particle/Solidification Front Interactions

Klein, H.	Particle Transport Induced by Directional Solidification	OSTA-2	6/18/83 11/28/83
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Gondi, P; Montanari, R.;	Bubble Reinforced Materials	SL-1	11/28/83
Barbieri, F.; Patuelli,	Directional Solidification Of Aluminium-Zinc Vapour Emulsion	SL-1	10/30/85
Potard, C.; Morgand, P	Melting And Solidification Of Metallic Composites	D-1	10/30/85
Deruyttere, A.; Froyen, L.	Particles at Melting and Solidification Fronts	D-1	10/30/85
Langbein, D.; Roth, U.	The behaviour of Aluminum Oxide Particles at the Solidification Front of Copper	D-1	9/12/92
Poetschke, J.; Rogge, V.	Preparation of Ni Base Dispersion Strengthened Alloys, M-6	SL-J	9/12/92
Muramatsu, Yuji	Fabrication of Very Low Density - High Stiffness Carbon Fiber/Al Hybridized Composites	SL-J	6/20/96
Suzuki, Tomoo	Interactive Response of Advancing Phase Boundaries to Particles	LMS	6/20/96
Hecht, U., Rex, S.	Particle Engulfment and Pushing by Solidifying Interfaces	LMS	11/19/97
Stefanescu, Doru, Sen, S.	Particle Engulfment and Pushing by Solidifying Interfaces	USMP-4	

### Skin Technology

			11/28/83
Luyendijk, T.; Nieswaag, H.;	Unidirectional Solidification Of Cast Iron	SL-1	11/28/83
Alsem	Skin Technology	SL-1	10/30/85
Sprenger, H.	Skin Casting on Grey Cast Iron	D-1	10/30/85
Nieswaag, H., Malinowska, M.	Skin Technology. Eutectic Solidification	D-1	4/26/93
Sprenger, H	Remelting of Nearly Eutectic Fe-C-X Alloys in a Ceramic Mold	D-2	4/26/93
Amende, W.	Skin		
Amende, W. Holl, S.	Remelting and Solidification of Turbine Blade	D-2	4/26/93
Busse, P; Deuerler, F.;	Influences on the Stability of Metal/Ceramic Dispersions with nm-Particles during Directional Solidification	D-2	
Poetschke, J.			

## CRYSTAL GROWTH EXPERIMENTS

### Bridgman Growth

			11/28/83
Rodot, M.; Tottereau, O.;	Lead-Telluride Crystal Growth Under microgravity Conditions	SL-1	10/30/85
Crouch, R. K.; Fripp, A. L. ;	Semiconductor Materials-Suppression of Body Force Gravity-Driven Convection in Directionally Solidified PbTe-SnTe	D-1	6/25/92
Debnam, W. J.	Crystal growth from the Melt Orbital Processing of High-Quality CdTe Compound Semiconductors	USML-1	6/25/92
Larson, D. J. ,et al	Crystal Growth of Selected II-VI Semiconducting Alloys by Directional Solidification	USML-1	6/25/92
Lehoczky, S. L. ,Andrews, R. N.;	The Study of Dopant Segregation Behavior During the Growth of GaAs in	USML-1	9/12/92
Bubulac, L. N.	Crystal Growth of Compound Semiconductors in a Low Gravity Environment, M22	SL-J	9/12/92
Matthiesen, D., Kafalas, J. ;	Bridgman growth of PbSnTe	SL-J	9/12/92
Motakef, S.	Fabrication of Si-As-Te:Ni Ternary Amorphous Semiconductor in the Microgravity Environment in Space , M-13	SL-J	4/26/93
Tatasumi, Masami	Convective effects on the growth of GaInSb crystals	D-2	3/4/94
Yamada, Tomoaki	Directional Solidification of Semiconductor Materials in Microgravity	USMP-2	10/20/95
Hamajawa, Yoshihiro	Orbital Processing of High-Quality CdTe Compound Semiconductors	USML-2	10/20/95
Duffar, T.; Garandet, J.P			
Lehoczky, Sandor			
Larson, David J.			

Lichtensteiger, M	Directional Solidification of Gallium-doped Germanium	USML-2	10/20/95
Matthiesen, D., Kafalas, J. ; Motakef, S.	The Study of Dopant Segregation Behavior During the Growth of GaAs in	USML-2	2/22/96
Fripp, Archibald L.;	Effects of Microgravity Direction on the Growth of PbSnTe	USMP-3	6/20/96
Duffar, T.	Effects of Convection on Interface curvature	LMS	11/19/97
Fripp, Archibald	Effects of Microgravity Direction on the Growth of PbSnTe	USMP-4	11/19/97
Lehoczky, Sandor; Gilles, Don	Solution Growth of GaAs Crystals under Microgravity	USMP-4	

### Growth by Traveling Zone

			11/28/83
Benz, K.W.; Nagel, G.	GaSb Semiconductor Crystals Under Microgravity; STS-9;	SL-1	11/28/83
Schönholz, R.; Nitsche, R.;	Solution Growth Of Cadmium Telluride	SL-1	10/30/85
Dian, R.			
Danilewsky, A.; Benz, Nagel, Notheisen, B	Growth of Single Crystals of Binary III-V Semiconductors by the Travelling Heater Method (Sulphur doped Indium-Phosphide)	D-1	10/30/85
Harr, M.; Dornhaus, R.;	Growth Of PbSnTe By The Travelling Heater Method	D-1	10/30/85
Brotz, G.			
Schoenholtz, R.; Dian, R.;	Growth of Cadmium Telluride by the Travelling Heater Method from Tellurium Solution	D-1	9/12/92
Nitsche, R.			
Segawa, Y.; Iwai	Growth of Pb-Sn-Te Single Crystal by Travelling-zone Method in Low	SL-J	4/26/93
Danilewsky, A. N.; Benz, K. W. ; Nagel, G.	THM - Growth of GaAs from Gallium Solutions	D-2	

### Growth by Floating Zone

			11/28/83
Eyer, A.; Leiste, H.;	Float Zone Crystallization of Silicon	SL-1	11/28/83
Nitsche, R.;			
Koelker, H.;	Crystallization of Silicon.	SL-1	10/30/85
Koelker, H	Crystallization of a Silicon Sphere	D-1	10/30/85
Croell, A.; Mueller, W.;	Silicon Crystal Growth by Floating Zone Technique	D-1	9/12/92
Nitsche, R.			
Nakatani, Isao	Growth of Semiconductor Compound Single Crystal by Floating Zone Method, M-3	SL-J	9/12/92
Nishinaga, Tatau	Growth of Si Sphere Crystals and the Surface Oxidation, M-9	SL-J	9/12/92
Takekawa, Shunji	Growth of Samarskite Single Crystal Under Microgravity	SL-J	4/26/93
Benz, K. W. ,Croell, A.;	Floating-Zone-Growth of GaAs	D-2	4/26/93
Nagel, G			
Camel, D.; Carlberg, T.;	Floating zone crystal growth of germanium.	D-2	4/26/93
Tison, P			
Herrmann, F. M.; Mueller, G	Single crystal growth of GaAs by the floating zone method on D-2	D-2	7/8/94
Hirata, A.	Mixing of a Melt of Multicomponent Compound Semiconductor	IML-2	

### Growth by Liquid Phase Epitaxy

			4/26/93
Suzuki, Y.; Kodama, S.	Growth of GaAs by liquid phase epitaxy	D-2	

## Growth the Vapor

			6/18/83
Wiedemeier, Herbert	Vapor Growth of Alloy-type Semiconductor Crystals	OSTA-2	11/28/83
Cadoret R.; Brisson P	Crystal Growth of Mercury Iodide by Physical Vapor Transport	SL-1	4/29/85
Cadoret R.; Brisson P.;	Crystal Growth of Mercury Iodide by Physical Vapor Transport	SL-3	4/29/85
Schneppe, W. F.	Mercuric Iodide Vapor Crystal Growth System (VCGS)	SL-3	10/30/85
Bruder, M.; Dian, R.;	Vapour Zone Crystallization of Cadmium Telluride	D-1	10/30/85
Nitsche, R.			
Launay, J.C	Solutal and Thermal Convection in Germanium-Iodine <sup>2</sup>	D-1	10/30/85
Wiedemeier, H.	Vapor Growth of Alloy-Type Crystals	D-1	1/22/92
Cadoret, R.;	Crystal Growth of Mercury Iodide by Physical Vapor Transport	IML-1	1/22/92
van den Berg, Lodewick	Vapor Crystal Growth System	IML-1	6/25/92
Wiedemeier, H.	Vapor Transport Crystal Growth of Mercury Cadmium Telluride	USML-1	10/22/92
Ruggeri, R. T.; Su, C. -H	Crystal Vapor Transport Experiment	USMP-1	4/26/93
Kimura, T.; Ono, H.,	Vapor Growth of InP Crystal with Halogen Transport in a Closed	D-2	10/20/95
Nishimura, T.; Mizuguchi,	Ampoule		
K., Murotani, T.			
Wiedemeier, Herbert	Vapor Transport Crystal Growth of Mercury-Cadmium-Telluride in Microgravity	USML-2	

## Growth from Aqueous Solution

			11/28/83
Galster, G.; Nielsen, K.F.	Crystal Growth From Solution	SL-1	11/28/83
Robert, M.C.; Lefeaucheux, F.; Authier, A.	Growth And Characterization Of Brushite And Lead Monctite	SL-1	4/29/85
Lal, R. B.	Fluid Experiment System (FES) Growth of Crystals in Solution	SL-3	1/22/92
Kanbayashi, A	Organic Crystal Growth Facility	IML-1	1/22/92
Lal, Ravindra B.	Solution Growth of TGS	IML-1	6/25/92
Kroes, R. L., Lehoczky, S. L.; Reiss, D. A.	Nucleation of Crystals from Solutions in a Low-g Environment	USML-1	6/25/92
Sacco, A.	Zeolite Glovebox Experiment	USML-1	6/25/92
Sacco, A., Dixon, A. G.;	Zeolite Crystal Growth	USML-1	9/12/92
Thompson, R. W.			
Anzai, Hiroyuki	Crystal Growth on Organic Metals in Low Gravity	SL-J	10/20/95
Sacco, Albert	Zeolite Crystal Growth	USML-2	10/20/95
Sacco, Albert	Zeolite GLOVEBOX Experiment	USML-2	

## Thermophysical Properties

### Diffusion Measurements

			11/28/83
Braedt, M.; Braetsch, V.;	Interdiffusion in the Glass Melt System (Na <sub>2</sub> O+Rb <sub>2</sub> O) <sub>3</sub> SiO <sub>2</sub>	SL-1	11/28/83
Frischat, G.H.			
Frohberg, G.; Kraatz, K.H.;	Selfdiffusion Of Sn <sup>112</sup> And Sn <sup>124</sup> In Liquid Tin	SL-1	11/28/83
Wever, H.;			
Malmejac, Y.; Praizey, J.P	Thermomigration of Cobalt in Liquid Tin	SL-1	2/3/84
Jeschke, V.; Frischat, G.H.	Gas Bubbles in Glass Melts	STS-41B	10/30/85
Dupuy, J.; Bert, J.; Moussa, I.; Henry; D.	Measurement of the Thermally Induced Ludwig-Soret Effects	D-1	10/30/85
Frohberg, G.; Kraatz, K.H.;	Atomic Diffusion and Transport in Liquid Metals	D-1	10/30/85

Wever, H.			
Merkens, W. (1); Richter, J.	Interdiffusion of Molten Salts	D-1	10/30/85
Praizey, JP	Thermoeffusion in Liquid Metallic Alloys	D-1	9/12/92
Dan, T.; Muramatsu, Y.	Diffusion in Liquid State and Solidification of Binary Systems	SL-J	4/26/93
Bert, J., Dupuy-Philon, J.	Soret effect measurement in a molten salt mixture in Space	D-2	4/26/93
Frohberg, G, Kraatz, K. H.; Wever, H.	Inter-Diffusion	D-2	4/26/93
Merkens, W. , Richter, J.; Afflerbach, K, Klessascheck, T.	Interferometric Determination of Differential Interdiffusion Coefficient of Binary Salts	D-2	4/26/93
Nakata, Y., Yasunaga, T., Yoshida, H.	Impurity Transport and Diffusion in InSb melt	D-2	4/26/93
Robert, M. C., Lefauchaux, F.; Bernard, Y.	IDILE: Measurements of Diffusion Coefficients in Aqueous Solution	D-2	4/26/93
Urbanek, J. , Hehenkamp, Th.	Diffusion of Nickel in Liquid Copper-Aluminum and Copper-Gold Alloys	D-2	7/1/97
Itami, Toshio	Diffusion of Liquid Metals and Alloys	MSL-1R	7/1/97
Uchida, M.	Diffusion in Liquid Lead-Tin-Telluride	MSL-1R	7/1/97
Yamamura, T.	Impurity Diffusion in Ionic Melts	MSL-1R	7/1/97
Yoda, S.	Measurement of Diffusion Coefficient by Shear Cell Method	MSL-1R	7/1/97
Matthiesen, D.	Diffusion Process in Molten Semiconductors	MSL-1R	

#### Undercooling Experiments

			1/12/86
Flemings, Merton C.	Electromagnetic Levitator	MSL-2	4/26/93
Wittmann, K., Otto, G.;	Nucleation and Phase Selection during Solidification of	D-2	7/8/94
Gillessen, F.	Undercooled Alloys		
Bayuzick, R. J.	Effects of Nucleation by Containerless Processing in Low Gravity	IML-2	7/8/94
Egry, I; Lohoefer, G.;	Viscosity and Surface Tension of undercooled Metallic Melts;	IML-2	7/8/94
Neuhaus, P; Feuerbacher, B			
Fecht, H. J.; Wunderlich, R.	Thermodynamics and Glass Formation in Undercooled Liquid	IML-2	7/8/94
K	Alloys		
Flemmings, Merton C.	Alloy Undercooling Experiments;	IML-2	7/8/94
Herlach, D. M.; Barth, M.;	Non-equilibrium solidification of largely undercooled melts	IML-2	7/8/94
Eckler, K.; Feuerbacher, B.;			
Gillessen, F.; Greer, A			
Johnson, W. L.	Metallic Glass Research in Space: Thermophysical Properties of Metallic Glasses and Undercooled Alloys	IML-2	7/8/94
Szekely, J.	Measurement of the Viscosity and Surface Tension of Undercooled Melts under Microgravity Conditions and Supporting Magnetohydrodynamic	IML-2	7/8/94
Urban, K.; Herlach, D.M.;	Structure and Solidification of Largely Undercooled Melts of	IML-2	7/1/97
Holland-Moritz, D	Quasicrystal-Forming Al .		
Bayuzick, Robert	Experiment on Nucleation in Different Flow Regimes	MSL-1R	7/1/97
Egry, Ivan	Viscosity and surface tension measurements in microgravity	MSL-1R	7/1/97
Fecht, Hans	Thermophysical Properties of undercooled Metallic Glass Forming Liquid Alloys	MSL-1R	7/1/97
Flemings, M. C, Trapaga, G.	Measurement of the Viscosity and Surface Tension of Undercooled Melts under Microgravity Conditions and Supporting Magnetohydrodynamic	MSL-1R	7/1/97
Flemings, M.C., Matson, D.M.	Alloy Undercooling Experiments	MSL-1R	7/1/97
Frohberg, Martin G.	Measurements of the Surface Tension of Liquid and Undercooled	MSL-1R	7/1/97

Herlach, D.M. Barth, M.	Metal Alloys by Oscillating Drop Technique, Dendrite growth velocity measurements in undercooled Ni and Ni-C melts in space,	MSL-1R	7/1/97
Herlach, D.M. Holland-Moritz, D.	Undercooled melts of alloys with polytetrahedral short range order	MSL-1R	7/1/97
Johnson, W.L.	AC Calorimetry & Thermophysical Properties of Bulk Glass-Forming Metallic Liquids	MSL-1R	7/1/97
Samwer, K., Damaschke, B. Egry	Thermal Expansion of Glass Forming Metallic Alloys in the Undercooled State	MSL-1R	

#### OPTICAL GLASS FORMING

Day, Delbert E.	Containerless Processing of Glass Forming Melts	OSTA-2	6/18/83
Braetsch, V.; Frischat, G.H.	Homogeneity of glasses	D-1	10/30/85
Day, D. E.; Ray, C. S	Containerless Processing of Glass Forming Melts-Determination of Critical Cooling Rates and Melt Homogenization	D-1	9/12/92
Hayakawa, Junji	Preparation of Optical Materials Used in Non-Visible Region	SL-J	9/12/92
Soga, Naochiro	Behavior of Glass at High Temperatures, M-8	SL-J	

#### MISCELLANEOUS EXPERIMENTS

Fukuzawa, A.	Formation Mechanism of Deoxidation Products in Iron Ingot Deoxidized with Two or Three Elements (M-5);	SL-J	32397
Wada, Nobuhiko	Gas-Evaporation Experiment in Low-Gravity Field (Congelation Mechanism of	SL-J	32397

## Biotechnology Experiments

### PROTEIN CRYSTAL GROWTH EXPERIMENTS

Littke, W.; John, C	Protein Crystal Growth	SL-1	11/28/8
Littke, W.	Protein Single Crystal Growth under Zero Gravity	D-1	10/30/8
Alexander McPherson	Protein Crystal Growth	IML-1	1/22/9
Charles E. Bugg	Protein Crystal Growth	IML-1	1/22/9
Littke, W	Single Crystal Growth of Beta-Galactosidase and Beta-Galactosidase/Inhibitor Complex	IML-1	1/22/9
Wagner, G	Crystal growth of the electrogenic membrane protein bacteriorhodopsin	IML-1	1/22/9
Birge, R.; Govender, D.	Formation of 3-Dimensional Bacteriorhodopsin Gels in	USML-1	6/25/9
Luttges, M. W.; Simske, S.;	Microgravity		
Stodieck, L			
Bugg, C. E. +50 CoI's	Protein Crystal Growth	USML-1	6/25/9
Chan, D.; Paulsen, A.;	Viral Protein Assembly in Microgravity	USML-1	6/25/9
Rottinghaus, S.; Johnson, T.;			
Consigli, R.			
DeLucas, L. J. + 50 CoI's	Protein Crystal Growth	USML-1	6/25/9
Todd, P.; Sportiello, M.,	Protein Crystal Growth Habit	USML-1	6/25/9
Luttges, M. W.; Simske, S.;			
Stodieck, L			
Todd, P.; Sportiello, M.,	Lysozyme Crystallization by Osmotic Dewatering	USML-1	6/25/9
Luttges, M. W.; Simske, S.;			
Stodieck, L			
Todd, P.; Sportiello, M.,	Mass Crystallization of Lysozyme	USML-1	6/25/9
Luttges, M. W.; Simske, S.;			
Stodieck, L			
Bugg, C. E.	Protein Crystal Growth (PCG)	SL-J	9/12/9
Morita, Y.	Crystal Growth of Enzymes in Low Gravity	SL-J	9/12/9
Bugg, C. DeLucas, L., Long,	Commercial Crystal Growth	USMP-1	10/22/9
M.			
Erdmann, V. A.	Crystallization of Nucleic Acids and Nucleic Acid-Protein Complexes	D-2	4/26/9
Yonath, A., Hansen, H. A. S.	Crystallization of Ribosomal Particles	D-2	4/26/9
Carter, Daniel;	Protein Crystallization Apparatus for Microgravity (PCAM)	USMP-2	3/4/9
DeLucas, Lawrence;	Protein Crystal Growth (TES-VDA)	USMP-2	3/4/9
Chayen, N.E.; Gordon E. J.;	The crystallization of apocrustacyanin C1	IML-2	7/8/9
Zagalsky P.F.			
DeGrip, W.J. ;VanOostrum,	Crystallization of Visual Pigment Rhodopsin	IML-2	7/8/9
J. ;			
Broutin, I., Ries, M.,	Crystallization of Collagenase and Photoreaction Center under	IML-2	7/8/9
Ducruix, A	Microgravity		
Erdmann, V.A., Lorenz, S.	Crystallization of RNA Molecules	IML-2	7/8/9
Helliwell, J.	Studies of Lysozyme Protein Crystal Perfection from	IML-2	7/8/9
	Microgravity Crystallization,		
Yonath, A	Crystallization of ribosomal particles in space	IML-2	7/8/9
Martial, J.A.; Wyns, L.;	Crystallisation of Octarellins and copper oxalate	IML-2	7/8/9
Ng, J.D.; Lorber, B.;	Crystal Growth of a Thermophilic Aspartyl-tRNA Synthetase	IML-2	7/8/9
Théobald-Dietrich, A.; Kern,			
D.; Giegé, R.			
Sjoelin, L et al.	Crystal Growth of Ribonuclease A	IML-2	7/8/9



Wagner, G.; Rothaermel, T	Crystallization of Bacteriorhodopsin	IML-2	7/8/9
McPherson, A.	Microgravity Effects on Macromolecule and Virus Crystallization	IML-2	7/8/9
McPherson, A.	Protein Crystal Growth (GN2 dewar)	SL-M	6/27/9
Declercq, Jean-Paul	Crystal Structure Analysis of the Bacteriophage Lamda Lysozyme	USML-2	10/20/9
Carter, Daniel	Single-Locker Protein Crystal Growth-Two Methods	USML-2	10/20/9
Chayen, Namoi	Crystallization of Aprocystacyanin C	USML-2	10/20/9
De Grip, Willem	Crystallization of Visual Pigment Rhodopsin	USML-2	10/20/9
DeLucas, Larry	Protein Crystal Growth GLOVEBOX Experiment	USML-2	10/20/9
DeLucas, Larry	Commercial Protein Crystal Growth	USML-2	10/20/9
Ducruix, Arnaud	Crystallization of Monoclinic and Triclinic Lysozyme	USML-2	10/20/9
Erdmann, Volker	Crystallization of RNA Molecules Under Microgravity Conditions	USML-2	10/20/9
Giege, . Richard	Microgravity Crystallization of Thermophilic Aspartyle-tRNA Synthetase and Thaumatin	USML-2	10/20/9
Martial, Mainfroid	Crystallization in Space of Designed and Natural (a/b)-Barrel Structures, in Second United States Microgravity Laboratory	USML-2	10/20/9
McPherson, Alexander	Comparative Analysis of Thaumatin Crystals Grown on Earth and in Microgravity	USML-2	10/20/9
Sanger, Wolfram	The Structure of the Membrane-Embedded Protein Complex Photosystem	USML-2	10/20/9
Sjolin, Lennart	Crystallization of Glutathione S-transferase in Microgravity	USML-2	10/20/9
Wagner, Gottfried	Protein Crystal Growth: Light-driven Charge Translocation through Bacteriorhodopsin	USML-2	10/20/9
Weber, Wolfgang	Crystallization of Epidermal Growth Factor (EGF) Receptor	USML-2	10/20/9
Wyns, Lode	Crystallization in a Microgravity Environment of CcdB	USML-2	10/20/9
Yonath, Ada	Crystallization of Ribosomes	USML-2	10/20/9
Zagari, Adriana	Crystallization of Sulfolobus Solfataricus Alcohol Dehydrogenase	USML-2	10/20/9
Zagari, Adriana	A Comparison of Crystals Grown on Earth and in Microgravity in the Advanced Protein Crystallization Facility on the LMS Mission	LMS	6/20/9
McPherson, Alexander	Advanced Protein Crystallization Facility on the Life and Microgravity Sciences Mission	LMS	6/20/9
Chayen, Naomi	Crystallization of Crustacyanin Subunits	LMS	6/20/9
Betzel, Christian	Crystallization of EGFR-EGF	LMS	6/20/9
Wagner, Gottfried	Mechanism of Membrane Protein Crystal Growth: Bacteriorhodopsin - Mixed Micelle Packing at the Consolution Boundary, Stabilized in Microgravity	LMS	6/20/9
Helliwell, John	Monitoring of Lysozyme Protein Crystal Growth in Microgravity via aMach-Zehnder Interferometer and Comparison with Earth Control Data	LMS	6/20/9
Garcia-Ruiz, Juan	Growth of Lysozyme Crystals at Low Nucleation Density	LMS	6/20/9
Wyns,Lode	Crystallization in a Microgravity Environment on CcdB, a Protein Involved in the Control of Cell Death	LMS	6/20/9
Giegé, Richard,	Crystallization of Thermus Thermophilus AspRS	LMS	6/20/9
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Erdmann, Volker	Crystallization of Engineered 5S rRNA Molecules	LMS	6/20/9
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McPherson, Alexander	Hand-held Diffusion Test Cells	MSL-1R	7/1/9

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Okusawa, T.	Experiments Separating the Culture Solution of Animal Cells in High Concentration under Microgravity	IML-2	7/8/95
Sanchez, V ; Clifton, M., Schoot, B.	Protein separation by continuous-flow electrophoresis	IML-2	7/8/95
Sanchez, V.	Optimization of Protein Separation;	IML-2	7/8/95
Snyder, Robert	Electrohydrodynamic Sample Distortion	IML-2	7/8/95

**ELECTROFUSION**

Hampp, R. ; Hoffmann, E. ; Mehrlle, W. ; Naton, B. ; Reinhard, E.; Schnabl, H	Culture and Electrofusion of Plant Cell Protoplasts under Microgravity: Morphological/Biochemical Characterization	D-2	4/26/95
Zimmermann, U.; Klock, G.; Schnettler, R.; Neil, G. A.; Klinman, N. R.; Sammons, D. W.	Cell Culture, Cell Activation, Cell Fusion, and Hybridoma Production in Microgravity	D-2	4/26/95

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Bula, R. J, Zhou, W., Yetka, R. Draeger, N	Environmental Conditions in the Astroculture Plant Chamber	USML-2	10/20/95
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Stodieck, L., Robinson, M, Luttges, M	Commercial Generic Bioprocessing Apparatus	USML-1	6/25/95
Stodieck, L., Berryman, J, Wolfe, R	Commercial Generic Bioprocessing Apparatus	USML-2	10/20/95
Stodieck, L., Heyenga, A., Hoehn, A.	Astro/Plant Generic Bioprocessing Apparatus	MSL-1R	7/1/95

# Appendix B: References for Fluids and Combustion Experiments

## Fluids Experiments

### Capillarity Effects

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## Biomolecular Crystal Growth

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# REPORT DOCUMENTATION PAGE

*Form Approved*  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 8/18/99	3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE Spacelab Science Results Study, Executive Summary plus Vol.I - III			5. FUNDING NUMBERS	
6. AUTHORS R. J. Naumann (editor), C.A. Lundquist, E. Tandberg-Hanssen, J.L. Horwitz, G.A. Germany, J.F. Cruise, M.L. Lewis, and K.L. Murphy			C #NAS8-97095, TA #H-30194D	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Alabama in Huntsville 301 Sparkman Drive Huntsville, AL 35899			8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  NASA/Marshall Space Flight Center Marshall Space Flight Center, AL 35812			10. SPONSORING/MONITORING AGENCY REPORT NUMBER Unknown	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified/Unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  Beginning with OSTA-1 in November 1981, and ending with Neurolab in March 1998, thirty-six shuttle missions are considered Spacelab missions because they carried various Spacelab components such as the Spacelab module, the pallet, the Instrument Pointing System (IPS), or the MPSS. The experiments carried out during these flights included astrophysics, solar physics, plasma physics, atmospheric science, Earth observations, and a wide range of microgravity experiments in life sciences, biotechnology, materials science, and fluid physics which includes combustion and critical point phenomena. In all, some 764 experiments were conducted by investigators from the United States, Europe, and Japan. These experiments resulted in several thousand papers published in refereed journals, and thousands more in conference proceedings, chapters in books, and other publications. The purpose of this Spacelab Science Results Study is to document the contributions made in each of the major research areas by giving a brief synopsis of the more significant experiments and an extensive list of the publications that were produced. We have also endeavored to show how these results impacted the existing body of knowledge, where they have spawned new fields, and, if appropriate, where the knowledge they produced has been applied.				
14. SUBJECT TERMS Astrophysics, Solar physics, Plasma Physics, Atmospheric science, Earth Observations, Life Science, Biotechnology, Fluid Physics, Combustion, Critical Phenomena, Materials Science,			15. NUMBER OF PAGES 738	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT  Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE  Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT  Unclassified	20. LIMITATION OF ABSTRACT  SAR	

