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National and international space life sciences research programmes 1980 to 1993 - and beyond

Brian Fitton & David Moore

8.1 Introduction

In this Chapter we provide short summaries of the national research programmes in the space life sciences of the ESA member states, its associates and major international partners. The purpose is to provide complementary statistical information to the scientific content of earlier review Chapters. This Chapter also presents listings of the life science experiments carried out using the Space Transportation System (STS; the Shuttle), the collaborative research performed with the Russian Mir space station and the Foton recoverable satellite, as well as summaries of the ESA sounding rocket and parabolic flight programme experiments. The main listings cover the period 1980 to 1993. From this basic information it is possible to discern the overall emphasis and trends in the different research areas. Additional information may be found in the ESA Microgravity Database, operated by ESRIN.

In addition to these general data, which are essentially historic, the individual sections covering each of the national programmes summarizes the current activities and some of the plans for the future, where these have been clearly established. In several countries a strategic plan has been established for the future activities in the space life sciences, with specific focus. These plans are outlined where the information has been made available.

8.2 Austria

The research activities in the space life sciences in Austria lie principally in the human physiology area. They have developed slowly over the past decade, during which time Austria has hosted the *European Space Medicine and Biology Meeting* (1986) and the *Third European Symposium on Life Sciences Research in Space* (1987).

The culmination of that development was the AUSTROMIR mission, which took place in October 1991. This comprised ten individual experiments, covering neurophysiology, the cardiovascular and muscular system, genetics, and radiation dosimetry. Further details are given in Table 1.

Table 1. Space life sciences research in Austria

Topic	Title	Principal Investigator and/or authors	Affiliation
Disturbances in movement coordination following simulation with visual, acoustic and proprioceptive stimuli.	Eye-head-arm coordination and spinal reflexes in weightlessness (MONOMIR).	M. Burger, F. Gersten Brand *et al.* E. Hochmair, G. Steinwender I.B. Kozlovskaya, A. Sokolov *et al.*	Neurology Dept. And Physics Dept. Univ. Innsbruck IBMP, Moscow
Force-angle velocity relationship of musculature in/against predetermined translatory movement & correlation with integrated surface EMG.	Development and implementation of the MOTORMIR experiment on the Mir space station.	N. Bachl, R. Baron, K.H. Tschan, M. Mossaheb, W. Bumba, F. Hildebrand I. Kharitonov	Sports & Exercise Dept. Univ. of Vienna IBMP, Moscow
Measurement of attention, psychomotor speed, mental feasibility, time estimation, visuospatial perception, memory,	A study of cognitive functions in microgravity (COGIMIR).	T. Benk, F. Gerstenbrand B. Koserenko N. Watson	Neurology Dept. Innsbruck Univ. IBMP, Moscow Univ. Brit. Columbia

function changes.			
Accuracy of directional hearing and its role in human orientation in microgravity	Directional hearing in microgravity (AUDIMIR)	A. Persterer, C. Koppensteiner *et al*. M. Berger M. Nefjodova	AKG, Vienna Univ. of Innsbruck IBMP, Moscow
Examine the vertical vection illusion elicited by an optokinetic stimulator system.	Orientational effects from opto-kinetic stimulation (OPTOVERT).	C. Muller, G. Wiest, L. Deecke L. Kornilova	Neurology Clinic, Univ. Vienna IBMP, Moscow
'PULSTRANS' work time monitoring, and 'SLEEP' monitoring, of circulatory system. Influence of tremor parameters of the changes to muscle loading/ proprioreceptor threshold levels.	Monitoring of cardiovascular parameters during AUSTROMIR space flight The effect of microgravity on tremor (microvibration).	M. Moser, E. Gallasch, *et al.* R. Bayevskij, I. Funtowa *et al.* E. Gallasch, M. Moser *et al.* I.B. Kozlovskaya, M. Borlov	Physiolog. Inst., Univ. of Graz IBMP, Moscow Physiolog. Inst., Univ. of Graz IBMP, Moscow
Changes to dynamics of transcapillary fluid shifts studied by LBNP with sonic velocity measurement technique and measurement of volumetric, osmoregulatory & vasoactive hormone concentrations.	Altered fluid shift dynamics with 6 days in microgravity (body fluids).	H.G. Hinghofer-Szalkay *et al.* J. Schmeid, H. Heimel V.B. Noskov, I. Pestov, A.I. Grogorien	VRSM, Univ. Graz Lab. Messtechnik, Graz IBMP, Moscow
Thermoluminescent dosimeters and track etch foils to measure average LET and absorbed dose.	Radiation measurements inside the soviet space station Mir (DOSIMIR).	N. Vava, W. Schoewer, M. Fugger J. Akatov	ATOMINTS., Univ. of Vienna IBMP, Moscow
Investigation of genetic changes in lymphocytes, their possible repair and immunological effects.	Influence of microgravity on immune system and genetic information (MIRGEN).	H. Tuschl, *et al*. M.S. Chajdakow Y.J. Voronkov	Öst. Forsch. Zent. Sibersdorf IBMP, Moscow

Austria intends to continue with a modest research programme in the space life sciences, but has chosen to do this outside of the ESA Microgravity Programme. Consequently, Austria will not participate in the upcoming Euromir missions. Instead it intends to continue with direct cooperative research ventures with other countries. In particular it will continue to collaborate with Russia in the space life sciences.

8.3 Belgium

There is a small but active programme of space research in the life sciences in Belgium, primarily directed to human physiology. The areas of interest are indicated by the proposals which have been considered for future flight, mainly under the ESA *Columbus Precursor Flights* programme listed in Table 2. The experiment of Dr Schoeters, reflown on the Russian Foton biology spacecraft, will also be a candidate for a future Biopan experiment on Foton.

Table 2. Space life sciences research in Belgium: proposals highly recommended for future flight, mainly under the ESA 'Columbus Precursor Flights' programme

Title	Principal Investigator	Co-Investigators	Proposal no.
Changes in osteogenic marker gene expression and cytokine production	J.G.E.A. Bierkens, VITO, Flemish Inst. for Techn. Research, Mol, Belgium.	G. Schoeters R. van Vlasselner R. van den Heuvel VITO, Mol, Belgium	06
Effects of microgravity on the cytoskeleton, synthesis of extracellular molecules, and production of degenerative	C.M. Lapiere, Lab. de Dermatologie, University of Liege.	J.P. Soleilhavoup, University of Toulouse, France	518

enzymes in human fibroblast studies at a pre- and post-tranlational level.			
The influence of gravity on the differentiation and maintenance of fast and slow muscle fibres in skeletal muscle.	G. Marechal, Dept. de Physiologie, Univ. de Louvain.	G. Goldspink, Univ. of London. J.M. Gillis, Univ. de Louvain	383
Pulmonary function in microgravity.	M. Paiva, Inst. de Recherche, Interdiscip. Univ. de Bruxelles	L.A. Engel, Westmead Hospital, Australia. G.K. Prisk, H.J. Guy, J.B. West, UCLA, San Diego, U.S.A.	229
Biological dosimetry for cosmic radiation exposure during intra- and extra-vehicular activities in space, using haemopoietic stem cell functions.	G. Schoeters, VITO, Section Biology, Mol, Belgium	A. v.d. Heuvel, J. Bierkens, P. van Vlasselner, VITO. A. Poffijn, K. van Laere, J. Uyttenhove, NPL, Ghent.	81

The experiments of Dr Bierkens, Prof. Lapiere, and Prof. Paiva, together with an experiment of Prof. O. Quadens, University of Antwerp, on brain activity during sleep and waking in microgravity, were considered for flight on the Euromir 95 mission, that of Prof. Paiva being accepted. Interest in space life sciences in Belgium is increasing, and further proposals for new activities are expected as prospects for flights improve. Recent research reports published by the Belgian Science Policy Office, include:

The Respiratory System in Microgravity, by M. Paiva, which covered D-2 and SLS-1 results, using a respiratory inductive plethysmograph, together with data from parabolic aircraft flights. Equipment developed is intended for use on the Euromir 1995 flight. The work has been performed, in concert with the only three other groups involved in such research worldwide, in order to avoid duplication of effort. These are Prof. J.B. West, University of California, San Diego; Prof. D. Linnarson, Karolinska Institute, Stockholm (who performed complementary measurements on D-2) and Prof. V. Baranov, Institute of Biomedical Problems, Moscow.

Effects of Microgravity on Bone Cell Differentiation, by G.E.R. Schoeters & J. Bierkens covered the results obtained in the Bion 10 mission, during which the osteogenic activity of MN7 cell cultures was found to be reduced. Interleukin-1 and PTH elicited a larger response.

Sleeping and Walking in Microgravity, by O. Quadens, P. Dequae, R. Olieslagers & K. de Metz. This group has been involved in this type of research since the Spacelab 1 flight. Parabolic aircraft flights have been used to develop techniques and provide basic data in EEG, EMG, and EOG measurements during sleep periods.

8.4 Denmark

Life sciences space research in Denmark is currently concentrated on the DAMEC Research organization, which was established in 1988, primarily to promote space medical and human physiological research. The original formation was due to a nucleus of Danish research workers, who were involved in the preparation of medical experiments for the D-2 Spacelab mission, which took place in April/May, 1993.

There are now five full-time research staff in DAMEC, who have focused their research activities on investigations into the relationship between gravitational stress and the mechanisms of renal fluid and electrolyte handling in humans. The work is developed in collaboration with Danish medical university institutes and clinical departments.

This study of fluid volume control during changes in gravitational stress has involved ground based and space experiments, in which the cardiovascular, endocrine and renal variables have been measured. The group, and collaborators, undertook four experiments on the D-2 Spacelab mission, reporting on: (i) peripheral haemodynamics before and after weightlessness during lower body negative pressure in humans, O. Henriksen, P. Norsk & A. Gabrielsen; (ii) the central venous pressure during weightlessness, N. Foldager & P. Norsk; (iii) pulmonary stratification and compartment analysis with reference to microgravity, S. Groth, D. Merhild & F. Jessen; (iv) the influence of microgravity on endocrine and renal elements of volume homeostasis in man, P. Norsk, P. Bie, J. Warberg, N.J. Christensen & C. Stadeager.

Further experimental programmes, on Euromir 94 and Euromir 95, are: (i) influence of microgravity on osmo- and volume-regulation in man: dynamic responses to isotonic and hypertonic loads, P. Bie, C. Emmeluth, P. Norsk & N.J. Christensen; (ii) central venous pressure during weightlessness, N. Foldager & P. Norsk; (iii) influence of microgravity on renal fluid excretion in humans, P. Norsk & L.B. Johansen; (iv) central venous pressure during weightlessness, N. Foldager & P. Norsk.

Besides the DAMEC group, there is a group at the Institute of Molecular Biology, Aarhus University, under the leadership of Dr O. Rasmussen, which has been involved in space experiments on plant biology. On Bion-9, an experiment was flown on the effects of microgravity on the development of plant protoplasts in collaboration with Dr T.H. Iversen, of Trondheim University. The same group of collaborators carried out an experiment on IML-1, on the effect of microgravity environment on cell wall regeneration, cell divisions, growth, and differentiation of plants from protoplasts. Similar work was also performed during IML-2.

Future research within the DAMEC group is directed towards further study of the mechanisms of fluid volume control in humans. This work will be focused on the distribution of fluid between the interstitial and intravascular compartment, the pulmonary low pressure circulation and total circulatory space, and various low pressure intrapulmonary compartments. There will also be emphasis on the adaptation of total volume to short and long term microgravity and the regulating mechanisms. Ground based experiments have been, and continue to be, an important part of the programme and complement the space experiments.

8.5 France

The French strategies for future research in space biology and life sciences were the subject of a CNES organized seminar at Aix-en-Provence, in April 1991, which revised the 1985 Deauville seminar conclusions. The results of these deliberations are summarised in the following paragraphs.

8.5.1 Space biology

Space biology research was considered to have two basic approaches. The first is directed towards the preparations for the exploration of the solar system and this includes radiobiology, radioprotection, artificial ecosystems, and biology under low-gravitational acceleration. The second, and at present the principal approach, is that concerned with the fundamental biological responses to the space environment, including the gravitational responses (e.g. gravitropism), the potential role of gravity on genetic expression, energy transfer and effects of HZE particles, and the origin and development of life on Earth.

Four main research fields were defined, within that framework, namely: (i) exobiology; (ii) radiobiology; (iii) gravitational biology; and (iv) artificial ecosystems. Research objectives were established for each of these fields.

Exobiology. Main objective is understanding of processes leading to origin on life on Earth. Research topics identified are (i) chemistry of interstellar particles (including Antarctic micrometeorites) and planetary surfaces (Mars, Titan, comets), particularly with respect to the presence (or potential for synthesis) of early biochemical compounds (life seed theory); (ii) open exposure of macromolecules to the space environment.

Radiobiology. Principal objectives are characterisation of variations in the radiation environment (both spatial and time), risk assessment and biological implications, definition of preventive measures against radiation risks in space and development of methods for crew protection against space radiation. Subdisciplines identified include (i) physical radiodosimetry, cumulative doses (passive method comparable to Biostack) or on-line monitoring of HZE spectra (active dosimetry); (ii) (bio)chemical characterisation of DNA lesions by HZE particles; (iii) biological and genetic implications of cosmic radiation; cell inactivation, cell mutation and cell transformation (rodents being the preferred study animals).

Gravitational biology. Objectives here include gravity perception and related responses of biological structures at the cellular level and at the organism level. In particular this would include determination and expression of plant and animal bilateral symmetry (e.g. embryo polarity), the effects of varying gravity levels on the organisation of the cytoskeleton and possible effects on cell metabolism (e.g. biosynthesis, respiration). Research objects, or model organisms, identified were: (i) for developmental biology, filamentous algae, moss protonemata, *Drosophila* (fruit fly), marine invertebrates (e.g. ascidia), the nematode *Caenorhabditis elegans*, and certain vertebrates (particularly some amphibia); (ii) for cell biology, both bacterial and animal cell cultures; (iii) in plant science, verification of existing models for cellular reception of gravity (e.g. in statocytes of roots) through experiments with amyloplast-free systems, transformed plants or non-gravitropic mutants.

Artificial ecosystems. The main objective identified here was assessment of the feasibility to construct artificial ecosystems. The recommended programme comprised a long-term construction plan for an artificial ecosystem aimed at supporting long-duration missions, and a supporting programme for short-duration experiments in simplified systems to investigate specific problems (e.g. maintenance and resource requirements). A number of special topics requiring investigation were identified. These were microbial populations, ecophysiology of plants and animals, long-term interaction of organisms, population dynamics and modelling, genetic population biology, autarchy of agricultural exploitation management, abiotic factors and potential exploitation of local resources.

8.5.2 Physiology

Physiology research in space was considered to be composed of six major fields: sensorimotor physiology (neuroscience), cardiovascular physiology and respiration, muscle physiology, bone tissue physiology, adaptation to the environment, and space medicine. With the intention that the research experiments be conducted on humans and/or animals (e.g. rodents, monkeys) the research objectives within the fields were identified as follows.

Sensorimotor physiology (neuroscience). Graviperception and motor coordination (e.g. ortholitic and muscular stimulation and posture); cognitive processes in microgravity (e.g. recognition of objects and body symmetries (particularly of the retina); concentration problems and electro-physiological patterns); modification of neurosensory structures (e.g. ortholitic organs, CNS, synapses); neuronal space adaptation problems (e.g. disorientation, space motion sickness).

Cardiovascular physiology and respiration. Orthostatic intolerance upon return (re-adaptation studies); neuro-vegetative regulation (e.g. of arterial pressure); mechanical regulation in low-pressure vascular systems; pharmacological experiments on physiopathology and medication/therapy); long-term responses of the cardiovascular system.

Muscle physiology. Mechanisms of muscle atrophy and related functional modifications; role of gravity in organisation, development, differentiation and regeneration of muscle tissues; development of prophylactic and rehabilitation methods.

Bone tissue physiology. Monitoring of bone loss (kinetics, reversibility, localisation, degradation of bone quality); mechanisms of bone loss (tissue level: bone tissue composition, bone restructuring in response to muscle contraction; cellular level: cell biomechanics, hormone influence on mineral metabolism and bone cell characteristics, e.g. proliferation and differentiation); development of bone tissue (e.g. osteoblasts) under microgravity; development of prevention methods against (i) bone degradation on long-duration space flights; and (ii) against osteoporosis.

Adaptation to the environment. Confinement effects on small closed groups (psychosocial studies); modification of neuro-endocrine and neurovegetative rhythms (e.g. circadian rhythms); behavioural and neuro-immuno-endocrine responses to stress conditions.

Space medicine: physiological and psychological issues. Medical aspects of crew selection and training; crew health maintenance during space flight; medical aspects of crew post-flight readaptation.

8.5.4 Life science experiment equipment and facilities

Table 3 summarizes the existing and planned facilities for the French research programmes in the life sciences, as of 1992. This list will be modified to take account of changes anticipated in future space programmes.

Table 3. Space life sciences research in France: existing and planned facilities for the French research programmes in the Space Life Sciences

Facility	Purpose	Status	Flight opportunity
	Human physiology & space medicine		
PHYSIOLAB	Echography, diuresis	on-going	Mir 92
	Medical monitoring of astronauts cardiovascular diagnoses; blood pressure, ECG, portable Doppler, spirometer, etc).	predevelopment studies	Mir 95
	Advanced PHYSIOLAB to include measurement of the biochemical parameters of blood and urine.	future development	
	Human physiology: neurosciences		
VIMINAL	Sensory-motor (eye/motion) coordination study, perception of the environment, body representation	on-going	Mir 92
VIVA	One eye or two eye optokinetic stimulator	on-going	Spacelab
SUPERPOCKET	Recording & monitoring of physiological signals on the body	on-going	Spacelab
OCULOMETER	Eye movement recording & restitution (pre- and post-flight measurements)	predevelopment studies	
ERGOMETER	(Pre- and post-flight measurements)	predevelopment studies	
COGNILAB	Cognition processes and performance assessment	predevelopment studies	Mir 96
KINESIGRAPH	Motion detection and analysis device	predevelopment studies	Neurolab, SLS-4
	Animal physiology as a model		

RHESUS	Monkey holding facility cooperation with NASA	on-going	SLS-3 & 4
Small animal holding facility	For rodents; technology study under way	future developments	
	Biology		
IBIS	Instrument for biological investigations in space	on-going	1st flight on Foton, reflight in Shuttle mid-deck
FERTILE	Developmental biology of amphibians	on-going	Mir 96
BIOREACTOR	Cell culture under microgravity	development studies	

8.5.5 French life science experiments in U.S. and Russian spacecraft, 1994 & 1995
Table 4 shows the recent, current and near-term missions involving French experiments in the life sciences, and some of the planned missions, while Table 5 summarizes the experiments which have been scheduled for flight in the near future on Russian spacecraft. In addition to such space experiments there is a continuing active programme of short duration microgravity experimentation carried out using sounding rockets and Caravelle-based parabolic flights.

Table 4. Space life sciences research in France: recent, current and near-term missions involving French experiments in the life sciences, and some of the planned missions

Programme	Objectives	Launch	Co-operation
	Biology		
Sounding rocket	Fertilization and development of sea urchin eggs. Internalizing of receptors (osteoblasts)	Launched in 1992	ESA
Biorack/IML-1	Resistance of bacteria to antibiotics.	Spacelab/IML-1 launched in 1992	ESA/ U.S.
Antares	Immunology of bacteria to antibiotics. Gravitropic response of plant roots.	Flight on Mir in 1992	Russia
Biocosmos 10	Osteoblasts and DNA lesions.	Launched in 1992	Russia
Altair	Immunology and exposure of biological samples to radiation.	Flight on Mir in 1993	Russia
Biopan	Exposure of samples to radiation (4 experiments).	Flight on Russian capsule in 1993	ESA
Biorack/IML-2	Gravitropic response of plants (lentils). Microenvironment and cellular activation.	Spacelab/IML-2 flights in 1994	ESA/U.S.
IBIS	Cellular biology.	Flight on Russian capsule in 1994 reflight in 1996	Russia
Cassiopea (Fertile)	Developmental biology of amphibians.	Flight on Mir 1996	Russia
	Physiology and Space Medicine		
Decubitus	Ground simulation: cardio-vascular weakening prophylaxis.	Short duration: 1993 Long duration: 1994	France ESA
Parabolic flight	Muscle, ethology	Campaigns completed in 1992	France
MVI EDO COIS	Vestibular Oculo Reflex (neurophysiology) EDO programme, Viva programme, COIS programme.	Mid-deck in 1992; 1993 Flight IML-1 in 1992 and 1994	U.S.

Biocosmos 10	Support tissues, psychological performance (attention and sleep)	Flight in 1992	Russia
Antares and Post Antares	Neurophysiology, cardio-vascular regulation, radiation protection, neurohormonal regulation	Flight on Mir in 1992	Russia
Altair	Neurophysiology, cardio-vascular regulation, radiation protection, neurohormonal regulation.	Flight on Mir in 1993	Russia
Spacelab/SLS	Space physiology in rats.	Spacelab/SLS-2 flights in 1993	U.S.
Echography	Cardio-vascular regulation.	Spacelab/D2 flight in 1993	ESA/U.S.
Rhesus	Space physiology in primates.	SLS-4 flights in 1998	U.S.
Neurolab	Dedicated mission for all neuroscience disciplines (Kinesiograph).	Spacelab/SLS-4 in 1998	U.S.
Cassiopea (Cognilab)	Cognition processes and performance assessment.	Flight on Mir 1996	Russia

Table 5. Space life sciences research in France: experiments scheduled for flight on Russian spacecraft

Experiment title	Principal Investigator	Co-investigators
	Euromir 94	
Posture and movement in microgravity.	A. Berthoz, LPN, CNRS, Paris	T. Pozzo, Univ. of Bourgogne J. McIntyre, LPN
‘STAMP’ Experiment - perception of figure symmetry by the two cerebral hemispheres.	A. Berthoz, LPN, CNRS, Paris	D. Viviani, University of Geneva, Switzerland
Spaceflight related orthostatic intolerance: role of autonomic nervous system, water balance, volume regulating hormones, and energy expenditure.	C. Gharib, Lab. de Physiol. de l’Environment, Faculté de Médicine, Lyon	A. Meillet, G. Gaugelin, A.M. Allevard, A. Pavy le Traon, Fac. de Médicine, Lyon. MEDES, Toulouse; R.L. Hughson, J.O. Fortrat, U. of Waterloo, Canada; J.P. Riou, C. Pacchiaudi, S. Normand. INSERM, Lyon.
Changes in mechanical properties of human muscle as result of spaceflight (ground experiment).	F. Goebel, Univ. de Technol. de Compiegne, Compiegne	J.F. Marini, Université d’Aix-Marseille
Bone mass and structure changes and bone remodelling in space.	C. Alexandre, L. Vico, Lab. de Biologie du Tissue Osseux, St. Etienne	
Influence of spaceflight on energy metabolism and its circadian variation.	H. Demaria Pesce, CNRS/INSERM, Inst. de Biologie du College de France, Paris.	S. Daan, Research Group Chronobiology, Haren; H. Visser, Centrum voor Isotopen Onderzoek, Groningen; J. Louis-Sylvestre, Univ. P. et M. Curie, Paris
Immune changes after space flight	D. Schmitt, Lab d’Immunologie, CHU Rangueil, Toulouse.	
	Euromir 95	
Changes in mechanical properties of human muscle during spaceflight.	F. Goubel, U. de Techn. de Compiegne, Compiegne	J.F. Marini, Univ. d’Aix-Marseille
Bone mass and structure measurements during long term spaceflight, using an ultrasound bone densitometer.	C. Alexandre, L. Vico, Lab. de Biologie du Tissue Osseux, St. Etienne	
	French experiments on Foton, 1995	
	Biobox	

To test whether *in vitro* cultures of osteoblast-like cells are gravity dependent in proliferation and activity	C. Alexandre	Lab. de Biologie du Tissue Osseux, St. Etienne
Biopan		
Survival of organic molecules under space conditions. Catalysis of reactions by solar U.V.	A. Brack	CBM, CNRS, Orléans
Radiation (HZE) induced base modifications in the cell genome.	J. Cadet	SESAM, MDS-CENG, Grenoble
Effects of cosmic radiation and microgravity on dormant shrimp embryos.	A. Hernandorena	Centre d'Etudes et de Recherches, Biarritz
Effects of cosmic radiation on isolated organic macromolecules. The effectiveness of radioprotective drugs.	J.P. Moatti	Université Paul Sabatier, Toulouse.
French experiments on Spacelab IML-2, 1994		
Effect of microgravity on cellular action: role of cytokines.	D. Schmitt	Lab. d'Immunologie, University of Toulouse
Cell microenvironment and signal transduction in microgravity.	P. Bouloc	Université de Paris, 7.
Effect of microgravity on lentil morphogenesis.	G. Perbal	Université de Paris, 6.
The sea urchin larva, a potential model for studying biomineralization and demineralization processes in space.	H.J. Marthy	Laboratoire Arago, Banyuls sur Mer

8.6 Germany

The German Space Agency (DARA) is responsible for defining the general strategic guidelines for space research and for implementing the German space programme by placing industrial contracts and funding of research groups. In addition, the agency represents Germany's space interests in the international arena.

With regard to the life sciences programme, the following goals and objectives have been defined: (i) to achieve fundamental scientific insights into the behaviour of biological systems under space conditions with emphasis on physical, chemical and physiological aspects; (ii) to contribute to the global exploration of the ecosystem of Earth by investigations of artificial ecosystems; (iii) to acquire the medical and technological fundamentals for the maintenance of humans in space; (iv) to contribute to terrestrial application-oriented and basic research, by improvements of existing technologies as well as by the development of novel methods and materials, and (v) to prepare for potential commercial utilization.

Essentially, life sciences research in space is seen as a natural extension of terrestrial research activities. It is therefore developed as an integral part of the terrestrial research fields. Focusing of research is encouraged, as is interdisciplinary cooperation. The national programme objectives are to be complemented by cooperative research programmes within ESA and specific international collaborations.

The programme goals, presented above, are sought whilst taking into account the following consideration: (i) success of theoretical and experimental work in the past; (ii) quality of scientific results gained so far; (iii) experiment proposals of very high scientific quality strongly recommended by peer groups; (iv) avoidance of redundant investigations by cooperative and complementary research; (v) objectives promising visible results in a shorter time frame, trying further to maximize the benefit.

Having established the basic goals, the priorities for future experimental facilities and the flight opportunities could then be defined. The following paragraphs summarize the current programme elements, for biology and for the field of human physiology.

8.6.1 Biology - current German programme

Gravitational biology. Role of gravity for growth, development, reproduction, movement, orientation and other physiological processes; mechanisms of adaptation and compensation; role of gravity for processes regulated by multiple factors; graviperception and signal reduction.

Bioregenerative life support systems. Development of life support systems for basic physiological research, involving: growth unit for higher plants, algal reactor for long term and multi-generation experiments, system for aquatic animals, development of microbial waste management systems and a combined system for investigation of the relationship between the botanical and zoological components, including system-theoretical problems (CEBAS).

Radiation biology. Passive and active dosimetric mapping of cosmic radiation; effects of cosmic radiation on biological material; interaction between cosmic radiation and microgravity.

Exobiology. Life under extreme environmental conditions; origin of life: role of cosmic factors.

Bioprocessing. Bioprocessing techniques: influence of space conditions, especially microgravity, on separation; and on cell fusion techniques; crystallization: growth of high quality monocrystals of biological macromolecules for the subsequent analysis of their structure.

8.6.2 Human physiology - current German programme

Cardiovascular system. Measurement of blood and fluid shift and analysis of the underlying regulatory principles.

Neurophysiology. Graviperception and gravisensitivity; space adaptation syndrome; neural integration and regulation, including neuronal plasticity.

Musculoskeletal system. Training and detraining effects on muscular structure and function; bone decalcification and alterations in connective tissues.

Endocrinology and metabolism. Measurement of hormones in order to obtain an integrative analysis of hormonal regulation; effects of space conditions on the immune system; dose responses and metabolism of medical drugs.

Operational space medicine. Human factors research: circadian rhythms, sleep-wake cycle and human performance; optimization of hygiene and food; isolation and confinement studies, psychological aspects of crew selection and crew training; development of countermeasures against space motion sickness and muscle and bone degradation; development of effective radiation protection in line with results from investigations in radiation biology.

8.6.3 Emphasis and focus in the German programme

Identifying the future focal areas, and looking to the timescale for each of these studies, the scheme shown in Table 6 has been developed.

Table 6. Space life sciences research in Germany: focal points in scientific research areas in the life sciences
Biology

	1992 – 1997 - 2002
Gravitational biology	physiological analysis biochemical & biophysical analysis of signal transduction chains
Bioregenerative life support systems	ground-based research (preparatory phase) ground-based reference programme for flight experiments flight experiments with plant & animal systems flight experiments BLSS
Radiation biology	passive dosimetric cosmic radiation detection active dosimetric cosmic radiation detection analysis of biological effects at morphological, physiological and molecular levels
Human physiology	
Cardiovascular system	measurement of blood and fluid shifts analysis of regulatory principles
Neurophysiology	analysis of graviperception and gravisensibility neuronal regulation and plasticity
Musculoskeletal system	training and detraining of muscular structures analysis of bone decalcification and alterations of connective tissues
Endocrinology and metabolism	measurement of particular hormones integrative analysis of hormonal regulation effect of space conditions on immune system and on responses to medical drugs
Operational space medicine	human factors research, e.g. circadian rhythms, sleep-wake cycle, performance isolation and confinement studies

A rough idea of the relative emphasis which is given to the different research areas is given by the number of projects funded (in 1993) in each of the various programmes by both DARA and by the DLR (Fig. 1). About 140 flight experiments involving German scientists have been performed in space biology and human physiology since the Apollo 16 flight of 1972; Fig. 2 shows the distribution of these experiments by research area. Many of these experiments were carried out within the flight programme listed in Table 7. Comparison of Figs 1 & 2 shows that research in gravitational biology continues to be a major activity - as indeed it is for ESA life science research as a whole. Radiation biology is also a continuing primary activity, together with research on the cardiovascular system. It is interesting to note also there has been a parallel effort on the more applied science topic of bioprocessing, which is continuing, although at a reduced relative level. A significant new activity is the work on bioregenerative life support systems, which now involves several research groups in Germany.

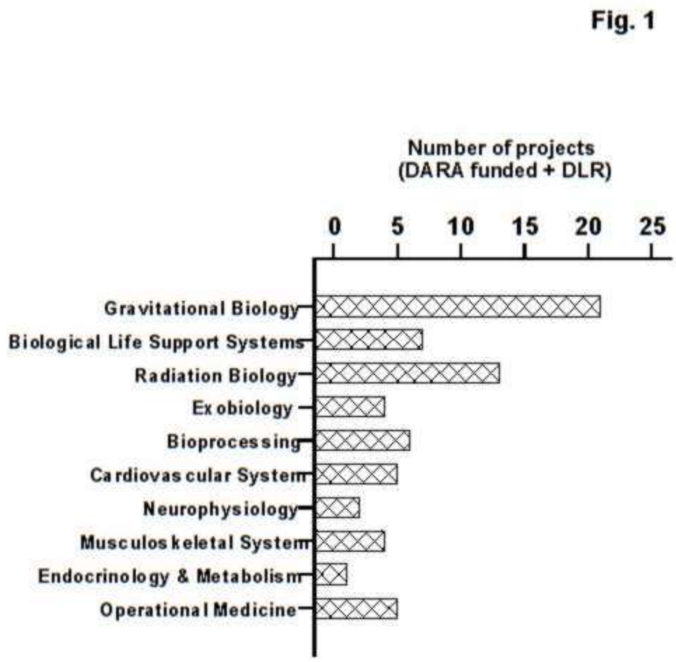

Fig. 1. Numbers of projects in the German space life sciences programme funded by DARA and DLR as of May 1993.

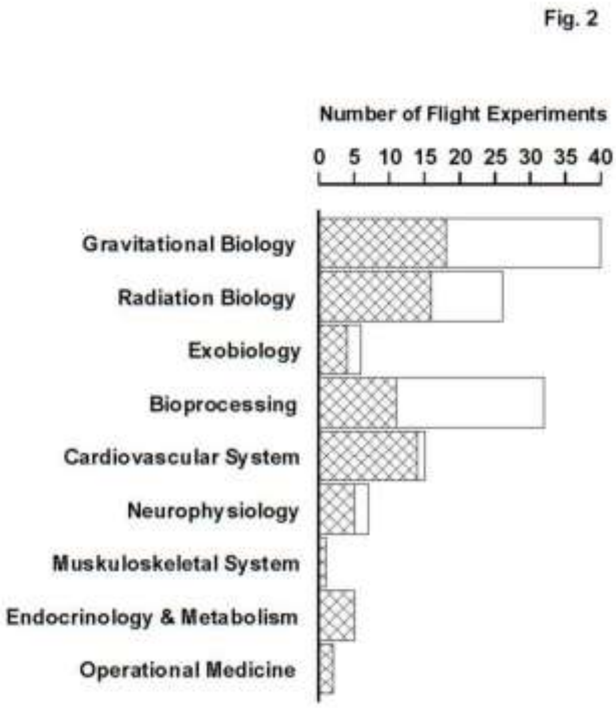

Fig. 2. Distribution of experiments performed by German scientists in space biology and human physiology between different research areas. Data covers 140 flight experiments performed since Apollo 16 (1972) to 1993. Experiments with European Principal Investigators are shown with cross-hatched shading.

Table 7. Space life sciences research in Germany: some milestones in German space life sciences research activities

Year	Mission	Remarks
1978	Salyut-6	First experiments in the Intercosmos programme during the first flight of a German crew member on a Soviet space station.
1983	First Spacelab mission	Four life science experiments, as well a being the first Spacelab mission with a

		German crew member.
1984	LDEF	The Long Duration Exposure Facility launched with German experiments in radiation biology and exobiology (retrieved in 1990).
1985	D1	14 experiments in life sciences during the first German Spacelab mission.
1986	MIKROBA	First launch of a balloon-borne drop capsule.
1987	Biocosmos 8	First life sciences experiment (radiation biology) on a re-entry satellite.
1991	Drop Tower	First experiments on gravitational biology in the Bremen Drop Tower.
1992	IML-1	Participation in the International Microgravity Lab Spacelab mission with 7 German experiments in life sciences and a German crew member.
1992	Mir 92	13 life sciences experiments (mainly on human physiology) during the flight of a German crew member on the permanently manned space station Mir.
1992	EURECA	7 life sciences experiments on an unmanned orbiting platform in the ESA microgravity programme.
1993	D-2	Second German Spacelab mission, with 30 life sciences experiments.
1994	Bion 10	3 biology experiments carried out, in collaboration with Russian and Mir experimenters, on its re-entry satellite
1994	IML-2	4 biology experiments (see Table 23).
In addition to these space experiments, there has also been an active programme of microgravity biology research carried out within the TEXUS sounding rocket programme, which started in 1977; see text.		

In addition to these space experiments, there has also been an active programme of microgravity biology research carried out within the TEXUS sounding rocket programme, which started in 1977. The TEXUS 29/30 launches, of 1992/93 contained 4 biology experiments. These are summarized below in order to give an illustration of the type of experimentation undertaken by this means.
(i) D.P. Häder (Univiversität Erlangen): *Gravitaxis and phototaxis in flagellates*. Third and fourth experiment to observe the movement and behaviour of gravitaxis in the motile unicellular alga *Euglena*, including phototactic reactions in microgravity.
(ii) A. Sievers (Univiversität Bonn): *Function of cytoskeleton in sedimentation of statoliths in Chara rhizoids.* Fourth and fifth experiment to investigate the cytoplasmic streaming under microgravity and to determine the role of cytoskeleton in graviperception of rhizoid cells.
(iii) R. Hampp (Univiversität Tübingen): *Effect of changes in gravitation on energy metabolism of plant cells.* The effect of short term microgravity conditions on the amount of adenine and pyridine nucleotides in plant protoplasts was investigated (second experiment).
(iv) H. Schnabl (Univiversität Bonn): *Protein pattern in mesophyll protoplasts of Vicia faba.* This first of a series of experiments investigated the effect of short duration microgravity on the pattern of special proteins in protoplasts as a marker for stress situations.

8.6.4 International collaboration in the German programme
International collaboration continues to be an important part of the overall German microgravity programme, and falls within the strategic guidelines for future planning of missions. The principal collaborations, as they have developed and current arrangements for future collaborative missions are as follows.

8.6.4.1 Collaboration with NASA
FSLP (1983); D-1 (1985); IML-2 (January 1992); D-2 (May 1993); IML-2 (1994); Get Away Special (GAS) programme with shuttle (BIOMAUS); mid-deck experiments under consideration; Spacehab; parabolic flights (KC-135); NASA/DARA-DLR LSPWG; sample sharing agreement; space life sciences training programme for students NSCORT programme.

8.6.4.2 Collaboration with ESA
Parabolic flights; sounding rockets (TEXUS/MAXUS); Bion; IML-1 1992 (Biorack, Biostack); Mir 92 (Vesta); D-2 1993 (Anthrorack); EURECA-1 1992/1993 (ERA); IML-2 1994 (NIZEMI, Biorack, Biostack); Euromir 94 and 95.

8.6.4.3 Collaboration with CIS Institutions
Mir 92 and Mir 92-E(xtension); Euromir 95; Re-entry satellites (Bion); agreement between DARA (DLR Institute of Aerospace Medicine) and ZPK, Moscow on cooperation in human physiology and operational medicine.

8.6.4.4 Collaboration with CNES
CNES/DARA Life Science Working Group; hardware sharing on CIS missions.

8.6.4.5 Collaboration with NASDA
Scientific working group; co-operative use of Drop Tower/Drop Shaft.

8.6.4.6 Collaboration with CSA
CSA/DARA Life Science Working Group.

The current international collaborations, at the scientific level, are listed in Table 8. Life science experimentation on the Russian Space Station Mir has played an important role in the German programme. Table 9 lists experiments carried out on Mir 92, and German experiments on Euromir 94 and Euromir 95.

Table 8. Space life sciences research in Germany: international collaborations, as at August 1993

Germany		Short title or Field of research	Collaborating country	
Scientist	University		Scientist	University
Space biology				
Machemer	Bochum	Gravitational sensitivity of microbes	Takahashi	Tokyo, Japan
Blüm	Bochum	C.E.B.A.S. - Aquarack Programme	Schreibman Doty Gitelson	New York, U.S.A. New York, U.S.A. Krasnoiarsk, Russia
Kranz	Frankfurt	Free Flyer Biostack, ESA Bion 10	Shevchenko Seitz Hellmann	Moscow, Russia Strasbourg, France Strasbourg, France
Sievers	Bonn	Growth and development of plants	Yamada Masuda Laurinavicius	Tokyo, Japan Osaka, Japan Vilnius, Lithuania,
Hampp	Tübingen	Electrofusion of plant cells	Outlaw Vasil	Tallahassee, U.S.A. Gainesville, U.S.A.
Schnabl	Bonn	Membrane physiology and electrofusion of cells	Bornmann	Lund, Sweden
Zimmermann	Würzburg	Electrofusion of cells	Sammons Neill	Arizona, U.S.A Iowa, U.S.A
Horneck	DLR	Radiation biophysics	Kozubek	Brno, CSFR
Space physiology				
StegemannDSHS College		Respiratory monitoring system	Swanson	Denver, U.S.A.
		O_2 uptake kinetic analysis	Hughson	Waterloo, Canada

von Baumgarten	Mainz	Vestibular physiology	Watanabe	Nagoya, Japan
		Cardio-vascular physiology	Blomquist	Dallas, U.S.A.
Baisch	DLR Cologne	Fluid shift	Baranov	IBMP Moscow, Russia
Wegmann	DLR Cologne	Countermeasures	Guell	MEDES Toulouse, France
Gundel	DLR Cologne	Sleep monitoring	Monk	Pittsburg, U.S.A.
Kirsch	FU Berlin	Fluid shift and metabolism	Matsui	Nagoya, Japan
		Tissue thickness and compliance	Kupzev	ZPK, Moscow, Russia
Scherer	FU Berlin	Vestibular-ocular-reflex	Kornilova	IBMP Moscow, Russia

Table 9. Space life sciences research in Germany: life science experiments on the Mir space station.

Experiment title	Investigators	Affiliation
Mir 92		
Self-tonometry under microgravity.	J. Draeger, R. Schwartz	University Hospital, Eppendorf
Effects of microgravity on interstitial muscle receptors affecting heart rate and blood pressure during static exercise.	D. Essfeld, K. Baum, U. Hoffmann, J. Stegemann	Physiological Institute Deutsche SporthochschulE, Cologne
Dosimetry in the space radiation field.	G.Reitz, R. Beaujean, N. Heckley, G. Obe	DLR, Institut Flugmedizin Univ. Kiel; Univ. G.H., Essen
Sleep and circadian rhythm during a short space mission.	A. Gundel, E.Reucher, M. Vejvodva, J. Zulley, V. Nalishiti	DLR, Inst. Luft- und Raumfahrtmedizin MPI Psychiatrie, Münich ZPK, Star City
Behavioural aspects of human adaptation to space analysis of cognitive and psychomotor performance.	D. Manzey, B. Lorenz, A. Schiewe, G. Finell G. Thiele	DLR, Inst. Luft- und Raumfahrtmedizin, DLR, Astronautenburo
Illusions of verticality in weightlessness	H. Mittelstaedt, S. Glasauer	MPI Verhalten-physiologie, Seewiesen; Neurolog. Klinik, Grosshadern, Münich
Vestibulo-oculomotor testing during space flight.	A.H. Clarke, W. Teiwes, H. Scherer	HNO Klinik, Klinikum Stieglitz, Free Univ., Berlin
Oculovestibular interactions under microgravity	K. Hoffstetter-Degen, J.Wetzig, R. Von Baumgarten	Physiolog. Institut J.G. Univ., Mainz
Responses to eccentric rotation in 2 space subjects.	K. Hoffstetter-Degen, J.Wetzig, R. Von Baumgarten	Physiolog. Institut J.G. Univ., Mainz
Reduced matriuresis during weightlessness.	R.Gerzer, C.Drummer, M.Heer, R.A. Dressendorfer, C.J. Strasburger	Klinik Innestadt, Münich + DLR, Flugmedizin
Fluid shifts into/out of superficial tissues under microgravity and terrestrial conditions.	K.A. Kirsch, F.J. Baartz, H.C. Gunga, L. Rocker	Inst. for Physiology, Free Univ. Berlin
Body fluid distribution in man; space and effect on LBNP treatment.	F.J. Baisch	DLR, Inst. Luft- und Raumfahrtmedizin, Cologne
Euromir 94		

Circadian rhythms and sleep during a 30-day space mission.	A. Gundel, A. Smael, A.M. Lebedjev, I. Ponomariova	DLR, Inst. Luft- und Raumfahrtmedizin. Inst. of Psychology, Moscow; IBMP, Moscow
Fluid and electrolyte balance during weightlessness and possibilities of their regulation.	C. Drummer, R. Gerzer, C. Kirschbaum, C.J. Strassburger	DLR, Inst. Luft- und Raumfahrtmedizin, Univ. Trier, Univ. Münich
Magnetic resonance spectroscopy imaging of human muscles before and after space flight (ground experiment).	J. Zange, K. Mueller, H. Schuber, A. Haase, V.S. Organov, B. Shenkmann	DLR, Inst. Luft- und Raumfahrtmedizin, Univ. Würzburg, IBMP, Moscow
Radiation health during prolonged space flight (environmental and personal dosimetry).	G. Reitz, R. Facius, H. Schäfer, J.U. Schott, R. Beaujean, W. Heinrich, C. Heilmann, E.E. Kovalev, V.E. Dudkin.	DLR, Inst. Luft- und Raumfahrtmedizin, Univ. Kiel, Univ. Siegen, Baen, Strasburg, S/C Rad. Safety, Moscow
Chromosomal aberrations in peripheral lymphocytes of astronauts (ground experiment).	G. Obe, N. Heckeley	Univ. Essen, Dept. of Genetics.
Fluid shifts into and out of superficial tissue-stability along the body axis.	K.A. Kirsch, H.C. Gunga, F.J. Baartz, L. Roecker	Inst. for Physiology, Free Univ., Berlin.
Effects of changes in central venous pressure on the erythropoietic system under 1 × g and microgravity.	H.C. Gunga, K. Kirsch, F. Baartz, L. Roecker	Inst. for Physiology, Free Univ., Berlin.
Spatial orientation and space sickness.	H. Mittelstaedt, S. Glasauer	MPI Verhaltenphysiol. Seewiesen. Lab. Physiol. Neurosens., Paris
Adaptation of basic vestibulo-oculomotor mechanisms to altered gravity conditions	H. Scherer	Universitaet Klinikum Stieglitz, Free Univ. Berlin
Gastroenteropancreatic peptides during microgravity and possible involvement in space motion sickness.	R.L. Riepl, C. Drummer, F. Fiedler	Klinikum Innenstadt, Univ. of Münich, Faculty of Clinical Medicine, Univ. Heidelberg
Non-invasive stress monitoring in space light by hormone measurements in saliva	C.J. Strasburger	Klinikum Innenstadt, Univ. of Münich,
	Euromir 95	
Monitoring of drug metabolism and drug effect during prolonged weightlessness	R. Gerzer, J. Wenzel, C.Drummer J.M. Heim, G. Wolf, V.S. Shashkov, H.B. Lakota, G.P. Stupakov	DLR, Inst. Flugmedizin, Univ. of Münich IBMP, Moscow
Radiation health during prolonged space flight.	G. Reitz, R. Facius, H. Schaeffer, J.U. Schott, R. Beaujean, W. Heinrich, C. Heilmann, E.E. Kovalev, V.E. Dudkin, I.A. Petrov	DLR, Inst. Fugmedizin Univ. Kiel, Univ. Siegen Baen, Strassburg, Res. Ctr, S/C Safety, Moscow IBMP, Moscow
Chromosomal aberrations in peripheral lymphocytes of astronauts.	G. Obe, N. Heckeley	Dept. Genetics, Univ. G.H. Essen
Magnetic resonance spectroscopy and imaging of human muscles and bones, before and after space flight.	J. Zange, K. Mueller, B. Topic, M. Schuber, A. Haase	DLR, Inst. Luft- und Raumfahrtmedizin; Univ. Wurzburg
Differential effects of otolith input on ocular lateropulsion, cyclorotation, perceived visual vertical, straight ahead, & tonic neck reflexes in man.	H. Dieterich, S. Krafczyk, T. Brandt, A. Straube	Neurology Department, Univ. of Münich

8.6.5 German experimental facilities

Principal experimental facilities developed to support biological and physiological research in space as part of the overall German microgravity programme are listed in Table 10, with their application and current status.

Besides experimental facilities, Germany has designated a number of centres of excellence to support and encourage specific focal areas of the space life sciences. These are: gravitational biology, AGRAVIS (University of Bonn); radiation biology, SCORT (University of Giessen); bioregenerative life support systems, CEBAS (University of Bochum); human physiology (Institute for Aerospace Medicine, DLR, Cologne).

Table 10. Space life sciences research in Germany: experimental facilities for biological and physiological research in space developed as part of the overall German microgravity programme.

Facility	Research Field	Mission	Status
BIOLABOR BB	Biological basic research		
Incubator 10-20° C with 1 × g reference centrifuge (STATEX)	Animal gravitational biology	D-1/D-2	available
Incubator 20-24° C with 1 × g reference centrifuge (BOTEX)	Plant gravitational biology/cell cultivation	D-2	available
Incubators 37° C with/without 1 × g reference centrifuge	Bioprocessing/cell cultivation	D-2	available
Electro cell fusion unit with workbench/microscope	Bioprocessing/electro cell fusion	D-2	available
Threshold centrifuge (THZ)	Gravitational biology	D-2	available
NIZEMI Slow-rotating centrifuge microscope	Gravitational biology	IML-2	available
BIOMAUS higher plant growth chamber	Gravitational biology	Small payloads programme	in development
CEBAS minimodule closed equilibrated aquatic system	Bioregenerative life support system	Small payloads programme	in development
SIMPLEX Incubator with 1 × g reference-centrifuge	Gravitational Biology	Small payloads programme	in development
MEDEX	Human physiology		available
Body impedance ECG measurement device	Cardiovascular physiology	Mir 92, D-2	available
Pulse and blood pressure measurement device			available
Applied potential tomography		Mir 92	available
Leg volume measurement device			available
Lower body negative pressure device (LBNP)	Operational space medicine		in development
Leg ergometer		Mir 92	available
TONOMETER	Cardiovascular physiology	Mir 92/D-2	available
VOG Mobile vestibular laboratory	Vestibular physiology	Mir 92, Mir 92-E	available
HSD tissue thickness and compliance	Cardiovascular physiology	Mir 92, D-2 Mir 92E	available

8.7 Holland

The Space Research Organisation of the Netherlands (SRON) supports a programme of microgravity life science research, with the emphasis on human physiology, cell and developmental biology, and the crystallization of proteins. Table 11 summarizes the experiments carried out during 1992 within this programme, which involved Russian as well as ESA/NASA space systems, together with ESA sounding rockets.

Table 11. Space life sciences research in Holland: experiments carried out during 1992.

Project title	Principal Investigator	Mission	Launch date
Effect of microgravity and mechanical stimulation on the *in vitro* mineralization and resorption of fetal mouse long bones.	J.P. Veldhuijzen, ACTA	IML-1	22 January
The role of gravity in the establishment of the dorso-ventral axis in the amphibian embryo.	G.A. Ubbels, Hubrecht Laboratory	IML-1	22 January
Bacterial proliferation under microgravity conditions.	C.L. Woldringh, UvA	IML-1	22 January
Regulation of cell growth and differentiation by microgravity.	A.J. Verkleij, UU; S.W. de Laat, Hubrecht Laboratory	MASER 5	9 April
Plasma membrane fusion in human fibroblasts during short term microgravity.	J.F. Jongkind, EUR	MASER 5	9 April
Photoprocessing of grain mantle analogues and shielding of spores.	M.J. Greenberg, RUL	EURECA	31 July
Vestibular rotation and nystagmus.	W.J.Oosterveld,AMC	ESA parabolic flights	March, April
Control of blood pressure in humans.	J.M. Karemaker, UvA	NASA parabolic flights	April
Effect of microgravity and mechanical stimulation on the *in vitro* mineralization and resorption of fetal mouse long bones.	J.P. Veldhuijzen, ACTA	Bion 10	29 December
Effects of microgravity on plasma membrane-cytoskeleton interactions during cell division in *Chlamydomonas*	H. v.d. Ende, UvA	Bion 10	29 December
Free running circadian rhythmicity during space flight	W.J. Rietveld, RUL	Bion 10	29 December

SRON support is now provided on an individual research topic basis, with fixed start and defined termination dates. Selection of research proposals was based on peer group reviews, apparently without any deliberate attempt to focus on specific life science research areas. At present an in depth re-evaluation of microgravity research projects is taking place. It is likely that this will lead to a focusing in the future on areas of cell biology, cardiovascular, and vestibular studies. During 1994, the existing programme will involve the reflight of the Bion-10 experiments of Professors Rietveld and van den Ende on the Foton spacecraft. There are also three Dutch experiments on the IML-2 mission; that of Dr G. A. Ubbels, on developmental biology, of Professor S.W. de Laat, on cell growth and differentiation effects in mouse embryonic cells, and of Dr J.P. Veldhuizen, studying *in vitro* mineralization and resorption of foetal mouse bones.

Dutch researchers will also be involved with the Euromir programme. For the Euromir 94 mission, Dr W. Bles, of the TNO Institute for Human Facilities, will be responsible for a ground experiment entitled *Does sickness induced by centrifugation mimic the Space Adaptation Syndrome?* This experiment will involve subjecting the crew to prolonged exposure to $3 \times g$ both before and after flight while recording blood pressure and other relevant parameters, including vestibular tests. Dr G.H. Visser, of the Isotope Research Centre and Dr S. Daan, of the Zoology Laboratory of Groningen University will be co-investigators in the experiment of Dr V. Demaria-Pesco, of CNES, Paris, entitled *Influence of space flight on energy metabolism and its circadian variation*.

For the Euromir 95 mission, Dr C. Vermeer of the Biochemistry Department, University of Limburg, has been selected to carry out an experiment entitled *Effect of Vitamin K supplements on bone mass during microgravity conditions*. An in-flight bone densitometer will be used, together with urine sample analysis, to observe the effects of administering vitamin K during flight. In addition to these space experiments, Dutch biologists have also been active in rocket based experimentation, and that activity will continue in the future.

8.8 Italy

The participation of Italian scientists in the microgravity life sciences programmes has been limited in the past, but is now developing as new opportunities become available. The main historical elements of Italian participation in space life sciences research, together with current plans and future developments in both long and short duration missions are given in Table 12.

Table 12. Space life sciences research in Italy.

Date	Flight	Title	Principal Investigators and collaborators	Affiliation
1983	Spacelab-1	3-D Ballistocardiography in space experiment in Spacelab.	A. Scano, V. Masini, F. Strollo, G. Brazzoduro, F. Prandi, C. Carna, E. Rispoli	University of Rome
1985	D-1	Effects of microgravity on genetic recombination in *Escherichia coli* (experiment on BIORACK).	O. Ciferri, O. Tiboni, A. M. Orlandoni, M. L. Marchesi	University of Pavia
1987	Parabolic flights	Performance of submaximal leg exercise in microgravity during parabolic flights.	D. Linnarsson, P.E. di Pram-pero, J. Stegemann, U. Hoffmann, D. Essfeld, C. Sunberg	Karolinska Institute Stockholm; Univ. of Udine; Univ. of Cologne, Univ. of Stockholm
1988	Parabolic flights	Effects of short term microgravity on the cardio-pulmonary function during exercise.	D. Linnarsson, P.E. di Prampero, G. Antonutto	Karolinska Institute, Stockholm; Univ. of Udine
1989/90	Parabolic flights	Blood lactate during leg exercise in microgravity.	P. Zamparo, C. Campbell, G. Antonutto	University of Udine
1990	MASER 4	Lymphoid cells in space.	A. Cogoli, M. Cogoli, N. Arena, S. Barri, P. Pippia, G. Monaco, L. Sciola, A. Spano, M. A. Meloni, R. Monti	Univ. of Sassari & Univ. of Naples
1992	MAXUS 1B	Lymphoid cells in space.	A. Cogoli, M. Cogoli, N. Arena, P. Pippia, G. Monaco, L. Sciola, A. Spano, M. A. Meloni, R. Monti	Univ. of Sassari & Univ. of Naples
1993	D-2	Effects of spaceflight on pituitary-gonad-adrenal function in humans (experiment for ANTHRORACK).	G. Riondino, F. Strollo, M. More, L. Bollanti, A. Ciarmatori, A. Scano, N. Mangrosse	INCRA University of Rome
1993	Parabolic flights	Effects of short duration microgravity. Cardiopulmonary function during sub-maximal leg exercise evaluated by means of the photo-acoustic analyser.	P.E. di Prampero, G. Antonutto, C. Capelli, P. Zamparo, M. Girardis	University of Udine
1993	Parabolic flights	Endocrine changes and motion sickness during parabolic flights.	E. Strollo, G. Giondino, M. More, L. Bollanti, A. Ciarmatori, T. Orsi, W. Mangrosse	INCRA University of Rome
1994	IML-2	Lymphoid cells in space	A. Cogoli, M. Cogoli, S.	University of Sassari

		(BIORACK on Spacelab).	Barri, P. Pippia, G. Monaco, L. Sciola, A. Spano, M. A. Meloni	
1994 and 1995	Euromir 94 Euromir 95	Effects of microgravity on the bio-mechanical and bioenergetic characteristics of human skeletal muscle (experiments on the ground, pre- and post-flight only).	P.E. di Prampero, G. Antonutto, C. Capelli, P. Zamparo, D. Linnarsson	University of Udine; Karolinska Institute, Stockholm
1995	Euromir 95	Interstitial fluid balance under microgravity, with special reference to pulmonary mechanics.	D. Negri	University of Milan
1995	MAXUS 2	Lymphoid cells in space.	A. Cogoli, M. Cogoli, P. Pippia, G. Monaco, L. Sciola, A. Spano, M.A. Melano	University of Sassari
1995?	MAXUS 2		Prof. Righetti	University of Milan
1996	MASER 7	Effects of microgravity on enzyme catalysis.	Prof. Vanni, Dr Lucarini	University of Firenze

8.9 Norway

At present there are three groups in Norway active in space life sciences research: (i) Dr T-H. Iversen, Department of Botany, University of Trondheim; Dr A. Johnsson, Department of Physics Department at the same University, and Dr R. Bjerkvig, Department of Anatomy, University of Bergen.

The Trondheim group have had experiments flown on Biokosmos 9 (1989) and the Space Shuttle, (IML-1) in 1992. These are listed in Tables 14 and 19. Further experiments were flown on IML-2 in 1994 (Table 23). The Trondheim group is also planning experiments for missions after 1995.

Research on IML-1 and 2 is concerned with: (i) studies of gravity perception on higher plants (experiment GTHRES); (ii) the effect of a microgravity environment on regeneration and differentiation of mature plants from protoplasts (experiment PROTO); (iii) the effects of microgravity on higher plants (experiment SHOOTS); root orientation, growth regulation and agravitropic behaviour of genetically transformed roots and regeneration of transgenic protoplasts (experiment TRANSFORM); spontaneous plant growth movements (experiment RANDOM) (see Tables 22 and 24).

The University of Bergen has proposed an experiment entitled *Neural cell development under microgravity conditions* which is now being evaluated for possible flight on Bion 11 in 1996.

8.10 Spain

The Comision Nacional de Ciencia y Tecnologia has established a National Space Plan which is intended to cover the general development of space related activities in Spain. It does not, however, reach down to the level of defining the details of a space life sciences programme. Instead, research activities are funded on an essentially ad hoc basis. Recently, there were only two active groups carrying out life sciences research in Spain. They are those of Professor R. Marco, Department of Biochemistry, Universidad Autónoma de Madrid and Professor J. Miquel, Institute of Neurosciences, Universidad de Alicante. These two groups have collaborated on earlier programmes.

The Madrid group is currently interested in two particular topics, deriving from work in the general field of developmental biology and aging. One is the identification and molecular genetic characterization of the main cytoskeletal and Ca^{++} binding proteins in the oocyte and early embryogenesis and muscle development. The other concerns the molecular genetic characterization of the mitochondrial components and machinery. Within these research interests, microgravity experiments may be performed where changes in gravitational acceleration could lead to a new perspective in the investigation.

Earlier work concerned development and aging, and the role of gravity in these basic processes. Several experiments were carried out. One in the Biorack on the Spacelab D-1 mission (1985), and another on the Bion-9 mission (1989), used *Drosophila melanogaster* fruit flies as experimental animals. The experiments were repeated on IML-1 in 1992, and extended on the Bion-10 mission in 1992. Proposals have been made for experiments using dormant *Artemia* (brine shrimp) cysts, for flight on Biopan and Biostack on IML-2.

Looking further to the future, the group is preparing the following programmes: (i) effect of the microgravity environment and cosmic radiation on the cytoskeletal organization of the oocyte and the early embryo, using *Drosophila* and *Artemia* as test systems; (ii) effects of microgravity and cosmic radiation on the patterns of cell proliferation and movements in the early *Drosophila* and *Artemia* embryo; (iii) study of the involvement of external/environmental forces in the acquisition of the morphological form of the *Artemia* nauplius larva; (iv) use of ground-based simulation equipment, clinostats and low speed centrifuges, to establish whether particular *Drosophila* mutants are more labile to the altered gravitational and/or radiation conditions found in space; (v) understanding the physiological and molecular response to microgravity in *Drosophila melanogaster* males.

In addition, efforts will be made to develop specific hardware in two categories: (i) following the development of the automatic unit for *Drosophila* mobility (DEMIR), to extend it to measure the oxygen consumption; (ii) explore the applications of microwaves in space biology, in staining, histoprocessing and sterilization.

8.11 Sweden

Space research in Sweden is conducted under the auspices of the Swedish National Space Board. The space life sciences research has been primarily undertaken by the Environmental Physiology Laboratory of the Karolinska Institute, in Stockholm. There the interest has focused principally upon the function of the lungs and upon the influences of long term exposure to microgravity on the control of arterial blood pressure during exercise and on the performance, structure, and biochemistry, of skeletal muscle.

An experiment *Pulmonary perfusion and ventilation in microgravity, under rest and exercise*, was carried out on the Spacelab D-2 mission in May, 1993 with Professor D. Linnarsson of the Karolinska Institute as Principal Investigator. This work will continue, with the experiment of Professor Linnarson entitled *Effects of short term and long term microgravity on the pulmonary gas exchange, respiratory and cardiovascular control during rest and exercise* being selected for the Euromir 95 mission.

That group was also involved, as co-investigators, on D-2 in the experiment *Determination of segmental fluid content and perfusion* by Dr F. Baisch, of DLR, and as co-investigators on SLS-1 in June, 1991. An active programme of ground based experiments is undertaken to study the effects of simulated weightlessness on the structural, metabolic, and functional properties of skeletal muscle, and cardiovascular control during rest and exercise in preparation for future flights.

Several parabolic flight experiments have also been conducted, the latest being to study the effects on blood circulation and gas exchange during the transition to microgravity in upright exercising subjects. It is also intended to test on a parabolic flight a gravity independent strength ergometer. This was designed by the group for resistance training of postural muscle, as an exercise countermeasure during long-term space flight.

8.12 Switzerland

There is no national Space Agency in Switzerland and no domestic programme set apart to support space activities. Access to ESA programmes is guaranteed by Switzerland’s status as a Member State of the Agency and bilateral cooperation with national agencies is also open to Swiss investigators. However they must compete with the rest of the scientific community for the financing of their experiments. An exception to this rule is the ESA Prodex programme, to which Swiss scientists can apply to seek funding for activities that include a major industrial component, and such support is being used also in the life sciences (e.g. the bioreactor project of Dr Cogoli on IML-2).

In the field of cell biology, space activities have been largely confined to the Space Biology Group of Dr A. Cogoli, at the Swiss Federal Institute of Technology in Zürich (ETH-Z). A space biologist from the early days, Dr Cogoli has flown several experiments on the Space Shuttle on Spacelab, on Biokosmos and on Mir, as well as on sounding rockets (MAXUS). His work has included investigating the effects of microgravity on cell differentiation processes (Friend leukaemia cells), cytoskeletal protein expression and organisation (fibroblasts) and cellular physiological responses (lymphocyte activation). Dr Cogoli has also participated in key technical developments for multi-user facilities such as Biorack.

In human physiology, Dr E. Fern (NESTEC Laboratories, Vevey) had an experiment measuring nitrogen turnover in the D-2 Spacelab mission astronauts. Currently, the Physiology Department of the University of Geneva (Drs Ceretelli, Ferretti and Kayser) is involved in experiments on Mir, dealing with respiratory and muscular physiology (using, amongst others, a Respiratory Monitoring System developed by the Swiss industry in cooperation with Dr Buess of ETH-Z), whereas Dr Ruegg (University of Fribourg) will have an experiment on the effects of exposure to microgravity on the preparation and execution of voluntary movements in connection with the Euromir 95 flight. In the field of bone physiology, the groups of Dr Uebelhardt (University of Geneva) and Stüssi (ETH-Z) have experiments on the Euromir 95 flight, and Dr Stüssi's Laboratory of Biomechanics is also developing a Torque Velocity Dynamometer and an instrument to monitor the resistance of long bones to fracture. In space-related sleep research, The Pharmacology Department of the University of Zürich (Drs Borbély and Tobler) has participated in EMSI/ISEMSI and in HYDRA IX experiments, supported by the Directorate of Space Station and Microgravity/Long Term Programme Office.

Finally, in human neurology, the group of Dr Viviani (University of Geneva) is actively cooperating with Dr Berthoz (CNRS, Paris) on the project STAMP which will investigate the perception of figure symmetry by the two cerebral hemispheres on the Euromir 94 flight.

8.13 United Kingdom

There is no U.K. National Programme for the microgravity life sciences, despite the interest of several research groups. Individual research has taken place by way of collaborations. Dr L.G. Briarty, of the Department of Life Science, University of Nottingham has worked together with Dr E.P. Maher of the University of Edinburgh, on the IML-1 Biorack experiment SHOOTS, flown in 1992. (See Trondheim Group, Sect. 8.9). Proposals have been made to extend this work on a future Spacelab or Mir mission. Dr A.J. Benson, of the RAF Institute of Aviation Medicine, Farnborough, is preparing to participate in experiments on Neurolab (1997). One experiment, originating from J.S.C., Houston, is concerned with investigating perceptual and vestibular responses to sustained linear acceleration (produced using the turntable flown previously on IML-1). The other concerns oculometer responses to linear oscillation, and is in conjunction with Dr Clarke of the Free University, Berlin.

U.K. scientists have participated in several parabolic flights, with Dr H. Ross of Stirling University involved in studies of human motor skills, Dr D. Grundy of Sheffield University observing the effects of body fluid shifts, and Dr J. Watkins of the University of Wales studying cerebral blood flow.

The Euromir programmes have also attracted interest from U.K. life scientists, with proposals from Dr D. Moore of Manchester University for Euromir 94, to study the gravitational rest state of fungal cells and embryonic rat calvaria cells. Two U.K. proposals for Euromir 95 have been accepted by ESA, both dealing with bone mass changes. That of Professor A. Goodship, of Bristol University, proposes the application of mechanical stimulation to prevent loss of bone mass during long term spaceflight. A study of the effect of venous pressure on bone mineral density in microgravity conditions was proposed by Dr I.D. McCarthy and Dr S.P.F. Hughes, of the Royal Postgraduate School, Hammersmith Hospital. Both of these studies will make use of the bone densimeter to monitor changes in flight.

In addition to these direct experimental activities, the group at Brunel University, under Prof. H. Wolff, have been involved in the design and development of experimental systems for the ESA life science programme, and Prof. Wolff was for several years Chairman of the ESA Microgravity Advisory Committee.

8.14 Hungary

ESA has a formal cooperation agreement with Hungary and also with Poland and Romania, to provide for studies of joint projects, access to laboratories and to databases. For the countries of Eastern Europe, the break-up of the Intercosmos organization has required a reappraisal of their space programmes and the collaborative arrangements. Agreements such as the one with ESA are a consequence of this process.

In Hungary, the new space research programme includes a space life sciences element, although first priority has been given to earth observations. In the life sciences, there is a new agreement with the Institute for Bio-Medical Problems (IBMP), Moscow, which will establish a common research programme.

Current space related research in the life sciences includes studies of the morphological and functional changes of the antigravity muscles in rats, of the adaptation mechanisms in the circulatory systems in humans, and the effects of microgravity on the mineral content of bone, using monkey subjects (with IBMP, Moscow). Studies of the sensorimotor adaptive processes have also used animal subjects.

In biology, there have been *in vitro* studies of animal cells in microgravity, and the interferon producing capacity of human lymphocytes *in vitro* and *in vivo*. Psychological research is also being undertaken into the effects of long term space flight, and radiation dosimetry experiments are included on Euromir 95.

8.15 Space life sciences research programmes of ESA and its partners

Tables 13 and 14 list all experiments which have been conducted on the Shuttle and Spacelab from 1981 onwards. We also present a summary of the experiments in biology and related subjects, carried out jointly with the USSR-CIS, in recent years in Tables 15 and 16. From these can be judged the actual relative emphasis of the ESA Life Sciences Programmes.

Table 13. Human life sciences (physiology and medicine) experiments on the Space Shuttle (1981-1993)

Mission	Flight	Launch	Experiment location	Experiment topic	Investigator	Affiliation
All STS-	Start STS-1	12-4-81	Mid-deck	Tests & counter measures for motion sickness; prediction/prevention of motion sickness	J.L. Homick	Med. Sci. Div. (NASA)
All STS-	Start STS-2	12-11-81		Cardiovascular deconditioning countermeasures	M.W. Bungo	Med. Sci. Div. (NASA)
DOD	STS-4	27-6-82	Mid-deck	Trivalent chromium level in the body; changes in chromium levels & carbohydrate metabolism.	K.R. Hauerspreger	Mecklenbury High School
DOD	STS-4	27-6-82	Mid-deck	Diet, exercise, zero-g, and lipoprotein profiles; lactic acid levels.	A.M. Kusske	Hill Jun. High School, CA
SBS-C	STS-5	11-11-82	To STS-8	Head and eye motion (ascent/entry);	W.E. Thornton	Astronaut

				vestibular function monitoring.		office,NASA
SBS-C	STS-5	11-11-82	To STS-8	On-orbit head and eye tracking tasks; motion sickness related studies/counter measures.	W.E. Thornton	Astronaut office, NASA
SBS-C	STS-5	11-11-82	& STS 7,8	Acceleration detection sensitivity; effect of zero-g on gain of otolith organs.	W.E. Thornton	Astronaut office, NASA
SBS-C	STS-5	11-11-82	& STS 7,8	Kinaesthetic ability; changes in neuromuscular system.	W.E. Thornton	Astronaut office, NASA
TDRS-A	STST-6	4-4-83	& STS 7,8	Body fluid shift; multiplanar photogram of lower to upper body fluid shift.	W.E. Thornton	Astronaut office, NASA
SBS-C	STS-5	11-11-82	& STS 6,7,8	Near vision acuity/contrast sensitivity.	J.M. Van der Ploeg	Space Biomed. Res. Inst. (NASA)
TDSR-A	STS-6	4-4-83	& STS 7,8	Audiometry; tympanic membrane compliance.	W.E. Thornton	Astronaut office (NASA, JSC)
SPAS-01	STS-7	18-6-83	& STS-8	Treadmill operation; cine film.	W.E. Thornton	Astronaut office (NASA, JSC)
SPAS-01	STS-7	18-6-83	& STS-8	Opthalmoscopic measurement of intracranial pressure.	E.L. Shuman	NASA (JSC)
SPAS-01	STS-7	16-8-83	& STS-8	Tissue pressure tonometry; fluid shifts, atrophy, muscle tone study.	W.E. Thornton	Astronaut office (NASA)
SPAS-01	STS-7	16-8-83	& STS-8	In flight countermeasures for SAS; tests of loading devices and of drug efficacy.	W.E. Thornton	Astronaut office (NASA)
PDRS	STS-8	30-8-83		Eye-hand coordination; sensory signals and motion sickness development.	W.E. Thornton	Astronaut office (NASA)
PDRS	STS-8	30-8-83		Anatomical observation; changes observed by palpation, aculation, percussion.	W.E. Thornton	Astronaut office (NASA)
PDRS	STS-8	30-8-83		Study of in flight fluid changes.	W.E. Thornton	Astronaut office (NASA)
PDRS	STS-8	30-8-83		Evoked potentials; auditory and visual measurements on 4 subjects.	W.E. Thornton	Astronaut office (NASA)
PDRS	STS-8	30-8-83		Intraocular pressure; changes measurements with applanation tonometer.	S.M. Pool	Medical Sci. Div. NASA
PDRS	STS-8	30-8-83		Soft contact lens application test; improving location of lens, for ocular motion tests.	W.E. Thornton	Astronaut office (NASA)
PDRS	STS-8	30-8-83	& 41 B	Pre/postflight parallel swing tests for self motion perception.	D.E. Parker	Miami University
PDRS	STS-8	30-8-83		Efficacy of biofeedback in sleep improvement.	W.A. Angelo	Arlington High School
SL-1	STS-9	28-11-83	Spacelab, Pallet	Radiation environment monitoring.	E.V. Benton	University of San Francisco
SL-1	STS-9	28-11-83	Spacelab	Miniature personal electrophysiological tape recorder for data on heart, brain, eyes.	H. Green	Clinical Research Centre, Harrow
SL-1	STS-9	28-11-83	Spacelab	Measurement of central venous pressure & hormones in blood	K.A. Kirsch	Free University of Berlin
SL-1	STS-9	28-11-83	Spacelab	Effects of space flight on erythrokinetics; study of cause of temporary anaemia.	C.S. Leach	Medical Sciences, Div. (NASA)

SL-1	STS-9	28-11-83	Spacelab	Vestibulospinal reflex mechanisms; study of alterations to otolith input and physiological adaptations.	M.F. Reschke	Space Biomed. Res. Inst. (NASA)
SL-1	STS-9	28-11-83	Spacelab	Mass discrimination during weightlessness.	H.E. Ross	University of Stirling
SL-1	STS-9	28-11-83	Spacelab	3-D ballistocardiography in weightlessness; comparison in cardiovascular performances.	A. Scano	University of Rome
SL-1	STS-9	28-11-83	Spacelab	Vestibular function and visual-vestibular interactions.	R. von Baumgarten	University of Mainz
SL-1	STS-9	28-11-83	Spacelab	Zero-g as a stress factor on immune response.	E.W. Voss jr.	University of Illinois
SL-1	STS-9	28-11-83	Spacelab	Sensory-motor adaptation, study of motion sickness	L.R. Young	Mass. Inst. of Technology
OSTA-3	STS-41-G	5-10-84	Mid-deck	Proprioceptive illusions during weightlessness.	D. Watt	McGill University, Montreal
OSTA-3	STS-41-G	5-10-84	Mid-deck	Awareness of limb position.	D. Watt	McGill University, Montreal
OSTA-3	STS-41-G	5-10-84	Mid-deck	Gastro-intestinal gas elimination.	D. Watt	McGill University, Montreal
OSTA-3	STS-41-G	5-10-84	Mid-deck	Measurements of vestibulo-ocular reflex; nervous system adaptation.	D. Watt	McGill University, Montreal
OSTA-3	STS-41-G	5-10-84	Mid-deck	Time course of space motion sickness.	D. Watt	McGill University, Montreal
OSTA-3	STS-41-G	5-10-84	Mid-deck	Alterations in tactile or proprioceptive functions.	D. Watt	McGill University, Montreal
OSTA-3	STS-41-G	5-10-84	Mid-deck	Changes in taste sensitivity.	D. Watt	McGill University, Montreal
	STS-41G, 41D, 51C, 51B	5-10-84	51B(SL/3)	Action of metoclopramide; relationship of bowel sounds to motion sickness	W.E. Thornton	Astronaut office (NASA)
	STS-41G, 41D, 51C	5-10-84		General visual performance changes in zero-g.	L.V. Genco	Wright-Patterson AFB
	STS-41G, 41D, 51B, C, D	5-10-84		Blood pressure monitoring on re-entry	W.E. Thornton	Astronaut office (NASA)
	STS-51C	24-1-85	Mid-deck	Aggregation of human blood cells.	L. Dintenfass	Kanematsu Inst. Univ. of Sydney
Telesat-1	STS-51D	12-4-85	Mid-deck	American flight echo cardiograph; cardiovascular deconditioning.	M.W. Bungo	Med. Sci. Division, NASA (JSC)
SL-3	STS-51B	29-4-85	Spacelab	Dynamic environment measuring system.	P. Callahan	Life. Sci. Fl. Expts. Office, NASA
SL-3	STS-51B	29-4-85	Spacelab	Autogenic feedback training (AFT) as a countermeasure to space adaptation syndrome.	P.S. Cowings	Neuroscience Branch, NASA (AMES)

SL-3	STS-51B	29-4-85	Mid-deck	Biotelemetry system; tested on rats (body temperature, heart rate, ecg).	C. Schatte	Life. Sci. Fl. Expts. Office, NASA
SL-3	STS-51B & STS-51J	29-4-85		LEG plethysmography; time course of leg volume changes/ fluid shifts.	T.P. Moore	Med. Sci. Division, NASA (JSC)
SL-3	STS-51B & 51J, 61C	29-4-85		Eye-hand coordination during space motion sickness.	W.E. Thornton	Astronaut office (NASA)
SL-3 SL-2	STS-51B & 51F	29-4-85	Spacelab	Combined blood investigation; fluid balance, SMS, and countermeasures	C.S. Leach	Med. Sci. Division, NASA (JSC)
Spin-1	STS-51G	17-6-85	Mid-deck	French postural experiment; sensorimotor adaptation (muscle tone, movement).	A. Berthoz	CNRS (Paris)
Spin-1	STS-51G	17-6-85	Mid-deck	French echocardiograph experiment; cardiovascular data on two crew.	L. Pourcelot	University of Tours
Spin-1	STS-51G & 51D, I, J, 61B	17-6-85	Mid-deck	Clinical characterization of SMS.	W.E. Thornton	Astronaut office (NASA)
SL-2	STS-51F	29-7-85	Mid-deck	Vitamin D metabolites and bone demineralization.	H.K. Schnoes	University of Wisconsin
SL-D1	STS-61A	30-10-85	Spacelab	Body impedance measurement; cardiovascular adaptation.	F. Baisch	DLR, Cologne
SL-D1	STS-61A	30-10-85	Spacelab	Tonometer; eye pressure changes.	J. Draeger	University of Hamburg
SL-D1	STS-61A	30-10-85	Spacelab	Gesture and speech in microgravity; communication aspects of cognitive behaviour.	A.D. Friederici	MPI, Nijmegen
SL-D1	STS-61A	30-10-85	Spacelab	Spatial description in space; effect of perception cues on communication on spatial arrangements.	A.D. Friederici	MPI, Nijmegen
SL-D1	STS-61A	30-10-85	Spacelab	Human reaction time (student experiment).	M. Hoschek	Muehtal
SL-D1	STS-61A	30-10-85	Spacelab	Central venous pressure; blood displacement in upper body.	K. Kirsch	Free University, Berlin
SL-D1	STS-61A	30-10-85	Spacelab	Mass discrimination.	H.E. Ross	University of Stirling
SL-D1	STS-61A	30-10-85	Spacelab	Vestibular research; response to optokinetic stimulation patterns.	R. von Baumgarten	University of Mainz
SL-D1	STS-61A	30-10-85	Spacelab	Vestibular research; perception of linear acceleration.	L.R. Young	MIT, Cambridge
EASE	STS-61-B & 61C	26-11-85	Mid-deck	Salivary acetaminophen. pharmacokinetics.	N.M. Cintron-Trevimo	Med. Sci. Division, NASA (JSC)
EASE	STS-61B	26-11-85	Mid-deck	Electropuncture in space.	F.Ramirez-Escalano	Secretaria de Communic.
MSL-2	STS-61C	12-1-86		Otolith tilt-translation reinterpretation.	M.F. Reschke	Med. Sci. Division, NASA (JSC)
MSL-2	STS-61C	12-1-86		Changes in total body water in first days.	C.S. Leach	Med. Sci. Division, NASA (JSC)
MSL-2	STS-61C	12-1-86		Non-invasive estimation of central venous pressure.	J.B. Charles	Med. Sci. Division, NASA

						(JSC)
MSL-2	STS-61C	12-1-86		In flight treadmill stress; documenting frequency of cardiac rhythm abnormalities.	M.W. Bungo	Med. Sci. Division, NASA (JSC)
MSL-2	STS-61C	12-1-86		In flight assessment of renal stone risk factor.	N.M. Cintron-Trevimo	Med. Sci. Division, NASA (JSC)
MSL-2	STS-61C	12-1-86		Echocardiographic evaluation of cardiovascular deconditioning.	M.W. Bungo	Med. Sci. Division, NASA (JSC)
LDEP-R	STS-32	9-1-90		American flight echocardiograph; size/functioning of heart (also flew on STS-51D).	M.W. Bungo	Med. Sci. Division, NASA (JSC)
SLS-1	STS-40	5-6-91	Spacelab	Weightlessness and autonomic cardio-vascular controls.	D.L. Eckberg	Medical College of Virginia
SLS-1	STS-40	5-6-91	Spacelab	In flight study of cardiovascular deconditioning; expiration-rebreathing and gas analysis.	L.E. Farhi	New York State University
SLS-1	STS-40	5-6-91	Spacelab	Motion sickness and inner ear vestibular changes.	L.R. Young	MIT, Cambridge, Mass.
SLS-1	STS-40	5-6-91	Spacelab	Protein metabolism during spaceflight; protein synthesis rates, muscle breakdown rates	T.P. Stein	Univ. of Med. & Dent. New Jersey
SLS-1	STS-40	5-6-91	Spacelab	Fluid-electrolyte regulation in spaceflight; immediate/long term changes to kidney function.	C.Leach-Huntoon	NASA (JSC)
SLS-1	STS-40	5-6-91	Spacelab	Pulmonary function during weightlessness.	J.B. West	Univ. California, San Diego
SLS-1	STS-40	5-6-91	Spacelab	Influence of spaceflight on erythrokinetics; mechanism leading to decrease in erythrocytes (and see SLS-2 = STS-58)	C. Alfrey	Baylor College of Medicine
SLS-1	STS-40	5-6-91	Spacelab	Cardiovascular adaptation to microgravity; catheter observations of fluid redistribution, echocardiograph, leg blood flow/compliance.	C.G. Blomquist	Southwest Med. Center of Texas
SLS-1	STS-40	5-6-91	Spacelab	Pathophysiology of mineral loss in space flight; levels of calcium metabolism, hormones, and of calcium.	C.D. Arnaud	Univ. California, San Francisco
IML-1	STS-42	22-1-92	Spacelab	Microgravity vestibular investigations; eye-object tracking, rotation perception, visual cues and vestibular response.	M.F. Reschke	NASA (JSC)
IML-1	STS-42	22-1-92	Spacelab	Mental workload and performance experiment.		NASA
IML-1	STS-42	22-1-92	Spacelab	Sled experiment, otolith stimulation/response; rotation experiment, coordination of head/eye movements; visual stimulation experiment, relationship between vision & balance organs; position/movement sensing of body.	D.G.D. Watt	McGill University, Montreal
IML-1	STS-42	22-1-92	Spacelab	Energy expenditure in space flight.	H.G. Parsons	University of Calgary

IML-1	STS-42	22-1-92	Spacelab	Positional and spontaneous nystagmus.	J.A. McClure	London Ear Clinic, Ontario
IML-1	STS-42	22-1-92	Spacelab	Evaluation of an anti-gravity suit; reduction of gravity induced effects on return	R.B. Thirsk	Canadian Space Agency
IML-1	STS-42	22-1-92	Spacelab	Assessment of back pain in astronaut; alleviate symptoms which result from spine elongation.	P.C. Wing	Univ. British Columbia
DSP	STS-44	24-11-91		Extended duration orbiter medical project; countermeasures and study of readaptive processes.	-	Med. Sci. Division, NASA (JSC)
ATLAS-1	STS-45	24-3-92		Changes in vision parameters: contrast ratio threshold.		Airforce Space Syst. Div. LA
Spacelab-J	STS-47	12-9-92	Spacelab	Autogenic feedback training experiment; biofeedback techniques as countermeasure for SMS.	P. Cowings	NASA (Ames)
Spacelab-J	STS-47	12-9-92	Spacelab	Lower body negative pressure; countermeasure for reducing post-flight orthostatic intolerance.	J.Charles	NASA (JSC)
Spacelab-J	STS-47	12-9-92	Spacelab	Magnetic resonance imaging after exposure to microgravity; muscle/bone changes	A. Leblanc	Methodist Hospital
Spacelab-J	STS-47	12-9-92	Spacelab	Endocrine and metabolic changes	Hismo Seo	Nagoya University, Japan
Spacelab-J	STS-47	12-9-92	Spacelab	Head/eye movements during visual tracking.	Kazuo Koga	Nagoya University, Japan
Spacelab-J	STS-47	12-9-92	Spacelab	Perceptual motor functions in zero-g.	Akira Tada	National Aerospace Laboratory, Japan
Spacelab-J	STS-47	12-9-92	Spacelab	Technology experiment: fluid therapy system; administration of intravenous fluids.		NASA
USML-1	STS-50	25-6-92	Spacelab	Extended duration orbiter medical project.	J.T. Brown	NASA (JSC)
LAGEOS-II	STS-52	22-10-92		Space vision system experiment (SVS).	H.F.L. Ankney	Nat. Res. Council, Canada
LAGEOS-II	STS-52	22=10-92		Space adaptation tests and observations (SATO); vestibular/ocular reflex, body water changes in microgravity, back pains in astronauts, illusion during movement.	D. Watt, H. Parsons, P.C. Wing	McGill Univ., Montreal, Univ. Calgary, Univ. British Columbia
DOD	STS-53			Visual function tester (model II); sensitivity of the eye to image contrast at threshold.	L. Task	Human Eng. Div. US Air Force, Ohio
D-2	STS-55	26-4-93	Spacelab	Peripheral & central haemodynamic adaptation to zero-g.	F. Bonde-Peterson	DAMEC
D-2	STS-55	26-4-93	Spacelab	Regulation of homeostatic volume in microgravity.	R. Gerzer	Univ. Münich, DLR & Univ. Heidelberg
D-2	STS-55	26-4-93	Spacelab	Cardiovascular regulation in microgravity; intravenous saline loading on induced fluid shifts.	G. Blomquist	University of Texas
D-2	STS-55	26-4-93	Spacelab	The central venous pressure in microgravity.	N.Foldager	DAMEC

D-2	STS-55	26-4-93	Spacelab	Leg fluid distribution at rest and under LBNP; changes following dehydration, disuse, and fluid shift.	F. Baisch	DLR (with TNO, Holland)
D-2	STS-55	26-4-93	Spacelab	Determination of segmental fluid content and perfusion.	F. Baisch	DLR (with TNO, Holland & Karolinska Inst. Sweden
D-2	STS-55	26-4-93	Spacelab	Left ventricular function, at rest and under stimulation	L. Beck	DLR (with Univ. Amsterdam & Univ. Tours)
D-2	STS-55	26-4-93	Spacelab	Tonometry -intraocular pressure in microgravity.	J. Draeger	Univ. Hamburg
D-2	STS-55	26-4-93	Spacelab	Tissue thickness & compliance along body axis in microgravity; new method to quantify fluid shifts within superficial tissue.	K.A. Kirsch	Fed. Univ. Berlin
D-2	STS-55	26-4-93	Spacelab	Influence of microgravity on carotid baroreceptor-cardiac reflex response.	D.L. Eckberg	
D-2	STS-55	26-4-93	Spacelab	Cardiovascular response to LBNP and fluid loading; mechanisms responsible for adverse reactions on landing.	L.Pourcelot	University of Tours, France
D-2	STS-55	26-4-93	Spacelab	Mechanism responsible for the negative nitrogen balance; changes in whole body nitrogen turnover rate, protein synthesis and breakdown.	E.B. Fern	NESTEC Ltd., Research Centre
D-2	STS-55	26-4-93	Spacelab	Effects of microgravity on glucose tolerance.	H.P. Maass	DLR,
D-2	STS-55	26-4-93	Spacelab	Influence of microgravity on endocrine & renal elements of volume homeostasis.	P. Norsk	DAMEC
D-2	STS-55	26-4-93	Spacelab	Effects of space flight on pituitary-gonadatrophin-adrenalin function; blood/urine/saliva analysis for signs of disturbance.	G. Riondino	INCRA, Italy
D-2	STS-55	26-4-93	Spacelab	Regulation of salt balance and blood pressure; role of volume regulatory hormones & plasma proteins.	L. Rocker	Fed. Univ. Berlin
D-2	STS-55	26-4-93	Spacelab	Pulmonary stratification & compartment analysis.	S. Groth	DAMEC
D-2	STS-55	26-4-93	Spacelab	Pulmonary perfusion & ventilation in microgravity.	D. Linnarson	Karolinska Inst.
D-2	STS-55	26-4-93	Spacelab	Ventilation distribution in microgravity.	M.Paiva	Univ. Brussels, Westmead Hospital, Australia & Univ. California
D-2	STS-55	26-4-93	Spacelab	Dynamics of gas exchange, ventilation, & heart rate in submaximal dynamic exercise; assessment of CO_2 kinetics as a monitor of endurance performance.	J. Stegemann	Deutsche Sport-Hochschule
EURECA Spacehab-1	STS-57	21-6-93	Spacehab	Neutral body posture; towards the design of future space facilities.	F.E. Mount	Flight crew support, NASA (JSC)
EURECA Spacehab-1	STS-57	21-6-93	Post-flight	Relation between mission duration and orthostatic functions; orthostatic function		NASA (JSC)

				during entry, landing, egress.		
EURECA Spacehab-1	STS-57	21-6-93	Spacehab	Visual vestibulary integration as a function of adaptation.		NASA
EURECA Spacehab-1	STS-57	21-6-93	Spacehab	Effects of intense exercise during space flight; action on aerobic capacity and orthostatic function.		NASA
EURECA Spacehab-1	STS-57	21-6-93		Pre and post flight measurement of cardiorespiratory response.		NASA
SLS-2	STS-58	Oct 93		Intermars tissue equiv. proport. counter.		Med. Sci. Division, NASA (JSC)
SLS-2	STS-58	Oct 93	Spacelab	Air monitoring instrument; evaluation and characterization of atmospheric microbial contaminants.		Med. Sci. Division, NASA (JSC)
SLS-2	STS-58	Oct 93	Spacelab	Energy utilization; caloric requirements for space flight.		Med. Sci. Division, NASA (JSC)
SLS-2	STS-58	Oct 93	Spacelab	Lower body negative pressure; conditioning cardiovascular system prior to re-entry.		Med. Sci. Division, NASA (JSC)
SLS-2	STS-58	Oct 93	Post flight	Orthostatic function during entry, landing, egress (continuing investigation - see STS-57).		Med. Sci. Division, NASA (JSC)
SLS-2	STS-58	Oct 93	Post flight	Evaluation of functional skeletal performance following space flight.		Med. Sci. Division, NASA (JSC)
SLS-2	STS-58	Oct 93	Post flight	Ability of crew to stand following landing		Med. Sci. Division, NASA (JSC)
SLS-2	STS-58	Oct 93	Post flight	Cardio-respiratory response to submaximal exercise.		Med. Sci. Division, NASA (JSC)
SLS-2	STS-58	Oct93	Spacelab	In flight study of cardiovascular deconditioning.	L.E. Fahri	New York Univ. at Buffalo
SLS-2	STS-58	Oct93	Spacelab	Cardiovascular adaptation to zero gravity.	C.G. Blomquist	S.W. Med. Center, Univ. Texas
SLS-2	STS-58	Oct 93	Spacelab	Pulmonary function during weightlessness.	J.B. West	Univ. California, San Diego
SLS-2	STS-58	Oct 93	Spacelab	Fluid-electrolyte regulation during space flight: changes in kidney action, salt/mineral balance, hormones	C. Leach	NASA (JSC)
SLS-2	STS-58	Oct 93	Spacelab	Influence of spaceflight on erythrokinetics; mechanism leading to decrease in erythrocytes (follow-on from SLS-1).	C. Alfrey	Baylor College of Med., Houston
SLS-2	STS-58	Oct 93	Spacelab	Vestibular experiments in Spacelab; six tests to assess sensory motor adaptation.	L.R. Young	MIT, Cambridge, Mass.
SLS-2	STS-58	Oct 93	Spacelab	Protein metabolism during space flight; study of synthesis/catabolism, & fibrinogen levels	T.P. Stein	N.J. Univ. Med., Dentistry

SLS-2	STS-58	Oct 93	Spacelab	Pathophysiology of mineral loss during space flight; role of vitamin d metabolites and calciotropic hormones	C.D. Arnaud	Univ. California, San Francisco

Table 14 (LEFT). STS-based biology missions, 1981-1993

[This table is a double page spread; the right-hand pages start on p. 41. To see the complete entry, note the row number and follow it to the right-hand page below]

Row No.	Mission	Flight	Launched	Carrier	Expt.	Topic	Title	Species or donor
1	OSTA-1	STS-2	12 Nov 81	Columbia	HBT	Processing equipment	HEFLEX bioengineering test	Dwarf sunflower
2	OSS-1	STS-3	22 Mar 82	Columbia	EEVT	Analysis equipment	Electrophoresis equipment verification Test	n.a.
3	OSS-1	STS-3	22 Mar 82	Columbia	HBT	Processing equipment	HEFLEX bioengineering test II	Dwarf sunflower
4	OSS-1	STS-3	22 Mar 82	Columbia	SE81-08	Graviperception (orientation)	Insect motion in space flight	Honey bee
5	OSS-1	STS-3	22 Mar 82	Columbia	SE81-08	Graviperception (orientation)	Insect motion in space flight	House fly
6	OSS-1	STS-3	22 Mar 82	Columbia	SE81-08	Graviperception (orientation)	Insect motion in space flight	Bean caterpilla r Moth
7	OSS-1	STS-3	22 Mar 82	Columbia	PGU	Growth and metabolism	Lignification in developing plant seedlings	Mung Bean
8	OSS-1	STS-3	22 Mar 82	Columbia	PGU	Growth and metabolism	Lignification in developing plant seedlings	Oat
9	OSS-1	STS-3	22 Mar 82	Columbia	PGU	Growth and metabolism	Lignification in developing plant seedlings	Pine
10	DOD	STS-4	27 Jun 82	Columbia	G-0001	Growth and metabolism	Algal microgravity bioassay experiment	
11	DOD	STS-4	27 Jun 82	Columbia	G-0001	Graviperception (Morphology)	Root growth of duckweed	Duckweed
12	DOD	STS-4	27 Jun 82	Columbia	G-0001	Effect on reproductive units	Microgravity effects on brine shrimp genetics	Brine shrimps
13	DOD	STS-4	27 Jun 82	Columbia	G-0001	Effect on genetic apparatus	Fruit fly experiment	Fruit fly
14	DOD	STS-4	27 Jun 82	Columbia	CFES	Analysis equipment	Continuous flow electrophoresis System	n.a.
15	SBS-c	STS-5	11 Nov 82	Columbia	SE81-02	Graviperception (morphology)	The growth of porifera in microgravity	Sponge
16	TDRS-A	STS-6	04 Apr 83	Challenger	CFES	Analysis equipment	Continuous flow electrophoresis system	n.a.
17	TDRS-A	STS-6	04 Apr 83	Challenger	G-0049	Growth and metabolism	Microorganism development	unspecifie d
18	TDRS-A	STS-6	04 Apr 83	Challenger	G-0049	Effect on reproductive units	Seeds in space	Fruit and vegetables
19	SPAS-01	STS-7	18 Jun 83	Challenger	CFES	Analysis equipment	Continuous flow electrophoresis system	n.a
20	SPAS-01	STS-7	18 Jun 83	Challenger	G-0002	Radiobiology (mapping)	Biostack	unspecifie d
21	SPAS-01	STS-7	18 Jun 83	Challenger	G-0002	Metabolism (Cd	Plant contamination by	Watercress

						transport)	heavy metals	
22	SPAS-01	STS-7	18 Jun 83	Challenger	G-0002	Graviresponse curve	Geotropism of sunflower sprouts	Sunflower
23	SPAS-01	STS-7	18 Jun 83	Challenger	G-0002	Insect communities	Orbit '81 (ant farm)	Carpenter ant
24	SPAS-01	STS-7	18 Jun 83	Challenger	G-0002	Graviresponse curve	Plant graviperception	Radish
25	PDRS	STS-8	30 Aug 83	Challenger	CFES	Analysis equipment	Continuous flow electrophoresis system	n.a.
26	SL-1	STS-9	28 Nov 83	Columbia	ES-027	Radiobiology (mapping)	Advanced Biostack experiment	Brine Shrimp
27	SL-1	STS-9	28 Nov 83	Columbia	ES-027	Radiobiology (mapping)	Advanced Biostack experiment	
28	SL-1	STS-9	28 Nov 83	Columbia	ES-027	Radiobiology (mapping)	Advanced Biostack experiment	Tobacco
29	SL-1	STS-9	28 Nov 83	Columbia	ES-027	Radiobiology (mapping)	Advanced Biostack experiment	Mouse-ear cress
30	SL-1	STS-9	28 Nov 83	Columbia	ES-027	Radiobiology (mapping)	Advanced Biostack experiment	
31	SL-1	STS-9	28 Nov 83	Columbia	ES-029	Exposure experiment	Microorganisms in hard space environment	
32	SL-1	STS-9	28 Nov 83	Columbia	ES-031	Growth and metabolism	Lymphocyte proliferation in weightlessness	Human
33	SL-1	STS-9	28 Nov 83	Columbia	NS-007	Endogenous rhythms	Characteristics of persisting circadian rhythms	
34	SL-1	STS-9	28 Nov 83	Columbia	NS-101	Graviperception (morphology)	Sunflower nutation in microgravity	Dwarf sunflower
35	SPAS-01A	STS-41B	03 Feb 84	Challenger	G-0008	Analysis equipment	Electrophoresis flow	n.a.
36	SPAS-01A	STS-41B	03 Feb 84	Challenger	G-0008	Gravity and phototropism	Phototropic effect on seedlings in microgravity	Radish
37	SPAS-01A	STS-41B	03 Feb 84	Challenger	IEF	Analysis equipment	Isoelectric focusing experiment	n.a.
38	SPAS-01A	STS-41B	03 Feb 84	Challenger	SE81-10	Bone and skeleton changes	Arthritis	Rat
39	LDEF-1	STS-41C	08 Apr 84	Challenger	SE82-17	Insect communities	Comparison of honeycomb structures	Italian honeybee
40	LDEF-1	STS-41C	08 Apr 84	LDEF		Radiobiology (mapping)	Free-flyer Biostack experiment	Brine shrimp
41	LDEF-1	STS-41C	08 Apr 84	LDEF		Radiobiology (mapping)	Free-flyer Biostack experiment	
42	LDEF-1	STS-41C	08 Apr 84	LDEF		Radiobiology (mapping)	Free-flyer Biostack experiment	Tobacco
43	LDEF-1	STS-41C	08 Apr 84	LDEF		Radiobiology (mapping)	Free-flyer Biostack experiment	Mouse-ear cress
44	LDEF-1	STS-41C	06 APR 84	LDEF		Radiobiology (mapping)	Free-flyer Biostack experiment	Maize
45	LDEF-1	STS-41C	06 APR 84	LDEF		Radiobiology (mapping)	Free-flyer Biostack experiment	
46	LDEF-1	STS-41C	06 APR 84	LDEF	SEEDS	Effect on reproductive units	Space-exposed experiment developed for students	Tomato

47	LDEF-1	STS-41C	06 APR 84	LDEF		Effect on reproductive units	Seeds in space experiment	various
48	OAST-1	STS-41D	30 Aug 84	Discovery	CFES	Analysis equipment	Continuous flow electrophoresis System	n.a.
49	OAST-3	STS-41G	05 Oct 84	Challenger	G-0007	Graviperception (morphology)	Study of the radish root system	Radish
50	TELESAT-1	STS-51D	12 Apr 85	Discovery	CFES	Analysis equipment	Continuous flow electrophoresis System	n.a.
51	TELESAT-1	STS-51D	12 Apr 85	Discovery	PPE	Analysis equipment	Phase partitioning experiment	n.a.
52	TELESAT-1	STS-51D	12 Apr 85	Discovery	SE82-03	Graviperception (morphology)	Statoliths in corn root caps	Maize
53	TELESAT-1	STS-51D	12 Apr 85	Discovery	SE83-03	Neurovestibular system (brain)	Aging of house fly brains	House fly
54	SL-3	STS-51B	29 Apr 85	Challenger	RAHF	Holding facility	Research animal holding facility	Squirrel monkey
55	SL-3	STS-51B	29 Apr 85	Challenger	RAHF	Holding facility	Research animal holding facility	Rat
56	SL-3	STS-51B	29 Apr 85	Challenger	BTS	Sensors and monitoring	Biotelemetry system	Rat
57	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Effectiveness of antibiotics	Effectiveness of antibiotics on bacteria	unspecified
58	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Effect on development	Growth of brine shrimp	Brine shrimp
59	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Growth of metabolism	Growth of soil mould	Soil mould
60	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Effect on germination	Growth of lettuce seeds	Lettuce
61	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Effect on germination	Germination of turnip seeds	Turnip
62	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Effect on genetic apparatus	Seed germination	Barley
63	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Growth and metabolism	Symbiotic growth of *Chlorella* and kefir	
64	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Growth and metabolism	Symbiotic growth of *Chlorella* and kefir	Yeast
65	SPTN-1	STS-51G	17 Jun 85	Discovery	G-0034	Regeneration (worm)	Planarian regeneration	Brown planarian
66	SL-2	STS-51F	29 Jul 85	Challenger	SL2-02	Growth and metabolism	Gravity-influenced lignification in higher plants	Mung bean
67	SL-2	STS-51F	29 Jul 85	Challenger	SL2-02	Growth and metabolism	Gravity-influenced lignification in higher plants	Oat
68	SL-2	STS-51F	29 Jul 85	Challenger	SL2-02	Growth and metabolism	Gravity-influenced lignification in higher plants	Pine
69	SL-D1	STS-61A	30 Oct 85	Challenger	071 DNA	Cell interaction	Microgravity and genetic recombination	
70	SL-D1	STS-61A	30 Oct 85	Challenger	071 DNA	Cell interaction	Microgravity and genetic recombination	
71	SL-D1	STS-61A	30 Oct 85	Challenger	15 E Fly	Insect communities	Fruit fly embryogenesis and life span	Fruit fly

72	SL-D1	STS-61A	30 Oct 85	Challenger	16 D Slime	Endogenous rhythms	Contraction and protoplasmic streaming	
73	SL-D1	STS-61A	30 Oct 85	Challenger	18 D Biostack	Radiobiology (effects)	Embryogenesis and organogenesis	Stick insect
74	SL-D1	STS-61A	30 Oct 85	Challenger	19 D Dosimeter	Radiobiology (mapping)	Dosimetric mapping inside Biorack	
75	SL-D1	STS-61A	30 Oct 85	Challenger	21 F Paramec	Growth and metabolism	Paramecium growth and mineral properties	
76	SL-D1	STS-61A	30 Oct 85	Challenger	21 F Paramec	Growth and metabolism	Paramecium growth and mineral properties	
77	SL-D1	STS-61A	30 Oct 85	Challenger	27 D Circadi	Endogenous rhythms	The biological clock of *C. reinhardii* in space	
78	SL-D1	STS-61A	30 Oct 85	Challenger	28 D Spores	Growth and metabolism	Bacterial growth and differentiation	
79	SL-D1	STS-61A	30 Oct 85	Challenger	32 CH Blood	Growth and metabolism	Human lymphocyte activation in weightlessness	Human
80	SL-D1	STS-61A	30 Oct 85	Challenger	33 CH Lympho	Growth and metabolism	Effect of microgravity on lymphocyte action	Human
81	SL-D1	STS-61A	30 Oct 85	Challenger	39 F Roots	Graviperception (growth)	Graviperception of lentil seedling roots	Lentil
82	SL-D1	STS-61A	30 Oct 85	Challenger	48 F Plasma	Graviperception (differentiation)	Ultrastructure of mammalian cell polarisation	Mouse
83	SL-D1	STS-61A	30 Oct 85	Challenger	52 NL Eggs	Fertilisation and embryogenesis	Dorso/ventral axis establishment in embryos	Clawed toad
84	SL-D1	STS-61A	30 Oct 85	Challenger	58 F Antibio	Effectiveness of antibiotics	Effectiveness of antibiotics under microgravity	
85	SL-D1	STS-61A	30 Oct 85	Challenger	BOT-01	Graviperception (growth)	Graviperception	Garden cress
86	SL-D1	STS-61A	30 Oct 85	Challenger	BOT-02	Graviperception (growth)	Geotropism	Maize
87	SL-D1	STS-61A	30 Oct 85	Challenger	BOT-03	Graviperception (differentiation)	Differentiation of plant cells	Anise
88	SL-D1	STS-61A	30 Oct 85	Challenger	STA-00	Graviperception (orientation)	Frog statolith experiment (STATEX)	Clawed toad
89	EASE	STS61B	26 Nov 85	Atlantis	CFES	Analysis equipment	Continuous flow electrophoresis system	n.a.
90	EASE	STS61B	26 Nov 85	Atlantis	Seeds	Graviperception (germination)	Effect of weightlessness and light on germination	Amaranth
91	EASE	STS61B	26 Nov 85	Atlantis	Seeds	Graviperception (germination)	Effect of weightlessness and light on germination	Lentil
92	EASE	STS61B	26 Nov 85	Atlantis	Seeds	Graviperception (germination)	Effect of weightlessness and light on germination	Wheat
93	EASE	STS61B	26 Nov 85	Atlantis	Repgrow	Growth and metabolism	Reproduction and growth of bacteria	
94	EASE	STS61B	26 Nov 85	Atlantis	Repgrow	Growth and metabolism	Reproduction and growth of bacteria	
95	EASE	STS61B	26 Nov 85	Atlantis	Transport	Growth and metabolism	Transportation of nutrients in weightlessness	Bean
96	MSL-2	STS-	12 Jan 86	Columbia	SE82-19	Hormone system	Auxin levels and starch	Maize

		61C				response	grains in roots	
97	MSL-2	STS-61C	12 Jan 86	Columbia	G-0007	Graviperception (morphology)	Study of the radish root system	Radish
98	MSL-2	STS-61C	12 Jan 86	Columbia	G-0332	Effect on reproductive units	Brine shrimp experiment	Brine shrimp
99	MSL-2	STS-61C	12 Jan 86	Columbia	G-0470	Effect on reproductive units	Gypsy moth and American Dog ticks	Gypsy moth
100	MSL-2	STS-61C	12 Jan 86	Columbia	G-0470	Effect on reproductive units	Gypsy moth and American Dog ticks	Dog tick
101	MSL-2	STS-61C	12 Jan 86	Columbia	G-0446 Joehus	Analysis equipment	High performance liquid chromatography	n.a.
102	TDRS-C	STS-26	29 Sept 88	Discovery	IEF	Analysis equipment	Isoelectric focusing electrophoresis	n.a.
103	TDRS-C	STS-26	29 Sept 88	Discovery	PPE	Analysis equipment	Phase partitioning experiment	n.a.
104	TDRS-D	STS-29	13 Mar 89	Discovery	Chromex	Regeneration (plant roots)	Chromosomes and plant cell division	
105	TDRS-D	STS-29	13 Mar 89	Discovery	Chromex	Regeneration (plant roots)	Chromosomes and plant cell division	Daylily
106	TDRS-D	STS-29	13 Mar 89	Discovery	SE82-08	Bone and skeleton changes	Effects of weightlessness on the healing bone	Rat
107	TDRS-D	STS-29	13 Mar 89	Discovery	SE83-09	Fertilisation and embryogenesis	Chicken embryo development in space	Chicken
108	Galileo	STS-34	18 Oct 89	Atlantis	GHCD	Hormone system response	Growth hormone concentration & distribution	Maize
109	LDEF-R	STS-32	09 Jan 90	Columbia	CNCR	Endogenous rhythms	Characterisation of *Neurospora* circadian rhythms	Pink Bread Mould
110	Ulysses	STS-41	08 Oct 90	Discovery	Chromex-2	Graviperception (differentiation)	Chromosomes and plant cell division	
111	Ulysses	STS-41	08 Oct 90	Discovery	PSE	Effectiveness of medication	Physiological systems experiment	Rat
112	GRO	STS-37	05 Apr 91	Atlantis	BIMDA	Processing equipment	Bioserve ITA materials dispersion apparatus	various
113	SLS-1	STS-40	05 Jun 91	Columbia		Bone and skeleton changes	Metabolic properties of skeletal muscle	Rat
114	SLS-1	STS-40	05 Jun 91	Columbia		Bone and skeleton changes	Bone, Calcium and space flight	Rat
115	SLS-1	STS-40	05 Jun 91	Columbia		Muscle changes	Skeletal myosin isoenzymes in rats	Rat
116	SLS-1	STS-40	05 Jun 91	Columbia		Muscle changes	Histochemistry and protease activities	Rat
117	SLS-1	STS-40	05 Jun 91	Columbia		Cardiovascular system	Regulation of blood volume during space flight	Rat
118	SLS-1	STS-40	05 Jun 91	Columbia		Cardiovascular system	Regulation of erythropoiesis during space flight	Rat
119	SLS-1	STS-40	05 Jun 91	Columbia		Graviperception (receptor)	Space travel and mammalian gravity receptors	Rat
120	SLS-1	STS-40	05 Jun 91	Columbia		Graviperception (receptor)	*Aurelia* ephyra differentiation and statolith synthesis	Jellyfish

121	SLS-1	STS-40	05 Jun 91	Columbia		Growth and metabolism	Lymphocyte proliferation in weightlessness	Human
122	SLS-1	STS-40	05 Jun 91	Columbia	G-0451	Effect on reproductive units	Flower and vegetable seeds space exposure	various
123	SLS-1	STS-40	05 Jun 91	Columbia	G-0451	Effect on reproductive units	Flower and vegetable seeds space exposure	various
124	TDRS-E	STS-43	05 Jun 91	Atlantis	BIMDA	Processing equipment	Bioserve ITA materials dispersion apparatus (BIMDA)	various
125	UARS	STS-48	12 Sept 91	Discovery	PARE-01	Muscle changes	Physiological & anatomical rodent experiment	Rat
126	DSP	STS-44	24 Nov 91	Atlantis	BFPT	Processing equipment	Bioreactor flow and particle trajectory	none
127	IML-1	STS-42	22 Jan 92	Discovery	02 NL Bones	Bone and skeleton changes	Mineralization and resorption of fetal bones	Mouse
128	IML-1	STS-42	22 Jan 92	Discovery	05 NL Eggs	Fertilisation and embryogenesis	Dorsal/ventral axis determination in embryos	Clawed toad
129	IML-1	STS-42	22 Jan 92	Discovery	07 E Fly	Insect communities	Development of *Drosophila* in space	Fruit fly
130	IML-1	STS-42	22 Jan 92	Discovery	08 DK Proto	Regeneration (full plant)	Plant differentiation from protoplast	Carrot
131	IML-1	STS-42	22 Jan 92	Discovery	08 DK Proto	Regeneration (full plant)	Plant differentiation from protoplasts	Rape
132	IML-1	STS-42	22 Jan 92	Discovery	10 D Morosus	Radiobiology (effects)	Embryogenesis and organogenesis	Stick insect
133	IML-1	STS-42	22 Jan 92	Discovery	12 D Dosimir	Radiobiology (mapping)	Dosimetric mapping inside Biorack	none
134	IML-1	STS-42	22 Jan 92	Discovery	13 D Spores	Growth and metabolism	Growth and sporulation of *Bacillus subtilis*	
135	IML-1	STS-42	22 Jan 92	Discovery	14 IML-1 Biostack	Radiobiology (mapping)	Dosimetric mapping with the Biostack	
136	IML-1	STS-42	22 Jan 92	Discovery	14 IML-1 Biostack	Radiobiology (mapping)	Dosimetric mapping with the Biostack	Yeast
137	IML-1	STS-42	22 Jan 92	Discovery	14 IML-1 Biostack	Radiobiology (mapping)	Dosimetric mapping with the Biostack	
138	IML-1	STS-42	22 Jan 92	Discovery	14 IML-1 Biostack	Radiobiology (mapping)	Dosimetric mapping with the Biostack	Brine shrimp
139	IML-1	STS-42	22 Jan 92	Discovery	14 IML-1 Biostack	Radiobiology (mapping)	Dosimetric mapping with the Biostack	Mouse-ear cress
140	IML-1	STS-42	22 Jan 92	Discovery	14.1 CH Friend	Growth and metabolism	Friend Leukaemia virus transformed cells	Human
141	IML-1	STS-42	22 Jan 92	Discovery	14.1 CH Friend	Growth and metabolism	Hybridoma cell proliferation and performance	Human
142	IML-1	STS-42	22 Jan 92	Discovery	14.3 CH Culture	Processing equipment	Dynamic cell culture system	Syrian hamster
143	IML-1	STS-42	22 Jan 92	Discovery	15 UK	Graviperception	Graviresponse of shoots and	Mouse-ear

					Shoots	(growth)	cotyledons in microgravity	cress
144	IML-1	STS-42	22 Jan 92	Discovery	16 IML-1 RMCD	Radiobiology (mapping)	Radiation monitoring container device	
145	IML-1	STS-42	22 Jan 92	Discovery	16 IML-1 RMCD	Radiobiology (mapping)	Radiation monitoring container device	Brine shrimp
146	IML-1	STS-42	22 Jan 92	Discovery	16 IML-1 RMCD	Radiobiology (mapping)	Radiation monitoring container device	Maize
147	IML-1	STS-42	22 Jan 92	Discovery	20 F Roots	Graviperception (growth)	Transmission of the gravity stimulus in roots	Lentil
148	IML-1	STS-42	22 Jan 92	Discovery	22 D Slime	Endogenous rhythms	Gravity related behaviour of *Physarum*	
149	IML-1	STS-42	22 Jan 92	Discovery	23 F Antibio	Effectiveness of antibiotics	Antibiotic penetration of bacterial cells in space	
150	IML-1	STS-42	22 Jan 92	Discovery	6 IML-1 FOTRA N	Graviperception (growth)	Seedling Response to Light Stimulation	Wheat
151	IML-1	STS-42	22 Jan 92	Discovery	6 IML-1 GTHRE S	Graviperception (growth)	Gravity sensor threshold of seedlings	Oat
152	IML-1	STS-42	22 Jan 92	Discovery	US-1 Radiat	Radiobiology (mapping)	Genetic and molecular dosimetry of HZE	Nematode
153	IML-1	STS-42	22 Jan 92	Discovery	US-2 Yeast	Effect on genetic material	Microgravity effects on chromosome behaviour	Yeast
154	IML-1	STS-42	22 Jan 92	Discovery	US-3 Cells	Bone and skeleton changes	Chondrogenesis in mouse limb mesenchyme	Mouse
155	IML-1	STS-42	22 Jan 92	Discovery	PPE	Analysis equipment	Phase partitioning experiment	n.a.
156	IML-1	STS-42	22 Jan 92	Discovery	G-0066	Effect on reproductive units	Brine shrimp in microgravity	Brine shrimp
157	ATLAS-1 STS-45	STS-45	24 Mar 92	Atlantis	STL	Effectiveness of medication	Space Tissue Loss	Rat
158	USML-1	SLS-50	25 Jun 92	Columbia	Astro-culture	Processing equipment	Astroculture (TM)	none
159	USML-1	STS-50	25 Jun 92	Columbia	GBA	Processing equipment	Generic bioprocessing apparatus	various
160	Eureca	STS-46	01 Aug 92	Atlantis	PHCF	Hormone system responses	Pituitary growth hormone cell function	Rat
161	Eureca	STS-46	01 Aug 92	Eureca	ERA	Exposure experiment	Exobiology and Radiation Assembly (ERA)	
162	Eureca	STS-46	01 Aug 92	Eureca	ERA	Exposure experiment	ERA	
163	Eureca	STS-46	01 Aug 92	Eureca	ERA	Exposure experiment	ERA	Yeast
164	Eureca	STS-46	01 Aug 92	Eureca	ERA	Exposure experiment	ERA	
165	Eureca	STS-46	01 Aug 92	Eureca	ERA	Exposure experiment	ERA	
166	Eureca	STS-46	01 Aug 92	Eureca	ERA	Exposure experiment	ERA	
167	SL-J	STS-47	12 Sept 92	Endeavour	L-12	Endogenous	Circadian rhythm of	Pink bread

						rhythms	conidiation	mould
168	SL-J	STS-47	12 Sept 92	Endeavour	L-2	Graviperception (orientation)	Posture and movement of fish in microgravity	Japanese carp
169	SL-J	STS-47	12 Sept 92	Endeavour	L-3	Analysis equipment	Separation of biogenic materials	n.a.
170	SL-J	STS-47	12 Sept 92	Endeavour	L-6A	Growth and metabolism	Ultrastructure and function of mammal cells	Monkey
171	SL-J	STS-47	12 Sept 92	Endeavour	L-6B	Growth and metabolism	Performance of antibody producing cells	Human
172	SL-J	STS-47	12 Sept 92	Endeavour	L-6C	Graviperception (differentiation)	Organ differentiation from plant cells	
173	SL-J	STS-47	12 Sept 92	Endeavour	L-7	Bone and skeleton changes	Calcium metabolism and bone formation	Chicken
174	SL-J	STS-47	12 Sept 92	Endeavour	L-8	Analysis equipment	Separation of cells and cell organelles	
175	SL-J	STS-47	12 Sept 92	Endeavour	L-9	Radiobiology (effects)	Genetic effects of HZE and cosmic radiation	Fruit fly
176	SL-J	STS-47	12 Sept 92	Endeavour	L-11	Radiobiology (mapping)	Biological effects of cosmic radiation	Maize
177	SL-J	STS-47	12 Sept 92	Endeavour	L-11	Radiobiology (mapping)	Biological effects of cosmic radiation	
178	SL-J	STS-47	12 Sept 92	Endeavour	L-11	Radiobiology (mapping)	Biological effects of cosmic radiation	Brine shrimp
179	SL-J	STS-47	12 Sept 92	Endeavour	FEE	Fertilisation and Embryogenesis	Embryology experiment	Clawed toad
180	SL-J	STS-47	12 Sept 92	Endeavour	FEE	Fertilisation and Embryogenesis	Embryology experiment	Clawed toad
181	SL-J	STS-47	12 Sept 92	Endeavour		Effect on genetic material	Plant culture research	Carrot
182	SL-J	STS-47	12 Sept 92	Endeavour		Effect on genetic material	Plant culture research	Daylily
183	SL-J	STS-47	12 Sept 92	Endeavour		Bone and skeleton changes	Bone cell growth and mineralisation	
184	SL-J	STS-47	12 Sept 92	Endeavour	ISAIAH	Insect communities	Investigation about hornets experiment	Oriental hornets
185	SL-J	STS-47	12 Sept 92	Endeavour	G-0255	Graviperception (differentiation)	Studies on cell formation in microgravity	
186	SL-J	STS-47	12 Sept 92	Endeavour	G-0255	Effect on reproductive units	Plant seed germination rates	
187	LAGEOS -11	STS-52	22 Oct 92	Columbia	CMIX	Commercial experiments	Commercial MDA ITA experiments	various
188	LAGEOS -11	STS-52	22 Oct 92	Columbia	PARLIO	Analysis equipment	Phase partitioning in liquids	n.a.
189	LAGEOS -11	STS-52	22 Oct 92	Columbia	PSE-02	Effectiveness of medication	Physiological systems experiment	Rat
190	TDRS-F	STS-54	13 Jan 93	Endeavour	ASPEC	Processing equipment	Preprogrammed experiment culture system	none
191	TDRS-F	STS-54	13 Jan 93	Endeavour	CGBA	Commercial	Commercial generic	various

						experiments	bioprocessing apparatus	
192	TDRS-F	STS-54	13 Jan 93	Endeavour	Chromex -3	Seed production	Chromosomes and plant cell division	Mouse-ear cress
193	TDRS-F	STS-54	13 Jan 93	Endeavour	PARE-02	Muscle changes	Physiological and anatomical rodent experiment	Rat
194	SL-D2	STS-55	26 Apr 93	Columbia	BB-IZL-Statex 11/1	Graviperception (orientation)	Vestibular reflexes in microgravity	Clawed toad
195	SL-D2	STS-55	26 Apr 93	Columbia	BB-IZL-Statex 11/1	Graviperception (orientation)	Vestibular reflexes in microgravity	Cichlid fish
196	SL-D2	STS-55	26 Apr 93	Columbia	BB-IZL-Statex 11/2	Graviperception (differentiation)	Development of the gravity perceiving organ	Clawed toad
197	SL-D2	STS-55	26 Apr 93	Columbia	BB-IZL-Statex 11/2	Graviperception (differentiation)	Development of the gravity perceiving organ	Cichlid fish
198	SL-D2	STS-55	26 Apr 93	Columbia	BB-IZL-Statex 11/3	Graviperception (differentiation)	CNS neuronal plasticity during ontogenesis	Clawed toad
199	SL-D2	STS-55	26 Apr 93	Columbia	BB-IZL-Statex 11/3	Graviperception (differentiation)	CNS neuronal plasticity during ontogenesis	Cichlid fish
200	SL-D2	STS-55	26 Apr 93	Columbia	BB-IZL-Statex 11/4	Graviperception (differentiation)	Cerebellar development in microgravity	Clawed toad
201	SL-D2	STS-55	26 Apr 93	Columbia	BB-IZL-Statex 11/4	Graviperception (differentiation)	Cerebellar development in microgravity	Cichlid fish
202	SL-D2	STS-55	26 Apr 93	Columbia	BB-IBT-Gravi	Graviperception (growth)	Gravisensitivity of cress roots	Garden cress
203	SL-D2	STS-55	26 Apr 93	Columbia	BB-IBT-Gravi	Graviperception (differentiation)	Cell polarity and gravity	Garden cress
204	SL-D2	STS-55	26 Apr 93	Columbia	BB-IBT-Gravi	Graviperception (differentiation)	Fruiting body development of fungi	
205	SL-D2	STS-55	26 Apr 93	Columbia	BB-IBT-Isa	Growth and metabolism	Secondary metabolites in cell suspensions	
206	SL-D2	STS-55	26 Apr 93	Columbia	BB-IBT-Yeast	Growth and metabolism	Investigation on yeast metabolism	Yeast
207	SL-D2	STS-55	26 Apr 93	Columbia	BB-ICC-Bact	Growth and metabolism	Productivity of bacteria	
208	SL-D2	STS-55	26 Apr 93	Columbia	BB-ICC-Bact	Growth and metabolism	Productivity of bacteria	
209	SL-D2	STS-55	26 Apr 93	Columbia	BB-ICL-Fluc	Effect on genetic material	Fluctuation test on bacterial cultures	
210	SL-D2	STS-55	26 Apr 93	Columbia	BB-ICL-Fluc	Effect on genetic material	Fluctuation test on bacterial cultures	
211	SL-D2	STS-55	26 Apr 93	Columbia	BB-ICC-Meta	Bone and skeleton changes	Collagen synthesis and cell proliferation	Human
212	SL-D2	STS-55	26 Apr 93	Columbia	BB-ICC-Cult	Growth and metabolism	Activation of regulatory T-lymphocytes	Human

213	SL-D2	STS-55	26 Apr 93	Columbia	BB-ICC-Grow	Growth and metabolism	Growth of lymphocytes in microgravity	Human
214	SL-D2	STS-55	26 Apr 93	Columbia	BB-EF-Hybrid	Cell electofusion	Cell fusion and hybridoma production	Human
215	SL-D2	STS-55	26 Apr 93	Columbia	BB-EF-Proto	Cell electrofusion	Electrofusion of plant cell protoplasts	Tobacco
216	SL-D2	STS-55	26 Apr 93	Columbia	BB-EF-Proto	Cell electrofusion	Electrofusion of plant cell protoplasts	Foxglove
217	SL-D2	STS-55	26 Apr 93	Columbia	BB-EF-Proto	Cell electrofusion	Electrofusion of plant cell protoplasts	Sunflower
218	SL-D2	STS-55	26 Apr 93	Columbia	RD-Bios	Radiobiology (mapping)	HZE-particle dosimetry with Biostack	Brine shrimp
219	SL-D2	STS-55	26 Apr 93	Columbia	RD-Bios	Radiobiology (mapping)	HZE-particle dosimetry with Biostack	Mouse-ear cress
220	SL-D2	STS-55	26 Apr 93	Columbia	RD-Bios	Radiobiology (mapping)	HZE-particle dosimetry with Biostack	
221	SL-D2	STS-55	26 Apr 93	Columbia	RD-Bios	Radiobiology (mapping)	HZE-particle dosimetry with Biostack	
222	SL-D2	STS-55	26 Apr 93	Columbia	RD-Bios	Radiobiology (mapping)	HZE-particle dosimetry with Biostack	Yeast
223	SL-D2	STS-55	26 Apr 93	Columbia	RD-Uvrad	Exposure experiment	Responses to solar UV and space vacuum	
224	SL-D2	STS-55	26 Apr 93	Columbia	RD-Uvrad	Exposure experiment	Responses to solar UV and space vacuum	
225	ATLAS-2	STS-56	06 APR 93	Discovery	CMIX-02	Commercial experiments	Commercial MDA ITA experiments	various
226	ATLAS-2	STS-56	06 Apr 93	Discovery	CMIX-02	Commercial experiments	Commercial MDA ITA experiments	various
227	ATLAS-2	STS-56	06 Apr 93	Discovery	PARE-03	Bone and muscle changes	Physiological and anatomical rodent experiment	Rat
228	ATLAS-2	STS-56	06 Apr 93	Discovery	STL-03	Effectiveness	Space tissue loss	Rat
229	Eureca -1R	STS-57	21 Jun 93	Endeavour	Astro-culture	Processing equipment	Astroculture (TM)	none
230	Eureca -1R	STS-57	21 Jun 93	Endeavour	BPL	Commercial experiments	Bioserve pilot laboratory - experiment 1	
231	Eureca -1R	STS-57	21 Jun 93	Endeavour	BPL	Commercial experiments	Bioserve pilot laboratory - experiment 2	
232	Eureca -1R	STS-57	21 Jun 93	Endeavour	BPL	Commercial experiments	Bioserve pilot laboratory - experiment 3	Frog
233	Eureca -1R	STS-57	21 Jun 93	Endeavour	CGBA	Commercial experiments	Commercial generic bioprocessing apparatus	various
234	Eureca -1R	STS-57	21 Jun 93	Endeavour	ORSEP	Processing equipment	Organic separation payload	n.a.
235	Eureca -1R	STS-57	21 Jun 93	Endeavour	PSE-03	Effectiveness of medication	Physiological systems experiment	Rat
236	Eureca -1R	STS-57	21 Jun 93	Endeavour	ASPEC	Processing equipment	Preprogrammed experiment culture system	
237	Eureca -1R	STS-57	21 Jun 93	Endeavour	G-450	Graviperception (germination)	Microgravity effects on sprouting seeds	

238	Eureca -1R	STS-57	21 Jun 93	Endeavour	G-450	Radiobiology (effects)	Effects of radiation on bacteria	
239	Eureca -1R	STS-57	21 Jun 93	Endeavour	G-450	Radiobiology (effects)	Bacteria survival in radiation	
240	Eureca -1R	STS-57	21 Jun 93	Endeavour	G-450	Radiobiology (effects)	Effects of radiation on seeds	
241	ACTS-TOS	STS-51		Discovery	Chromex -4	Graviperception (reproduction)	Seed production and forming in microgravity	Mouse-ear cress
242	ACTS-TOS	STS-51		Discovery	Chromex -4	Graviperception (differentiation)	Root and shoot development	Wheat
243	ACTS-TOS	STS-51		Discovery	Chromex -4	Graviperception (differentiation)	Cell wall forming and gene expression	Wheat

Table 14 (RIGHT). STS-based biology missions, 1981-1993

Row No.	Scientific name	Category	Key hardware	Investigator	Affiliation
1	*Helianthus annuus*	Plant	Sealed vials	A.H. Brown	UPA Philadelphia, PA
2	*n.a.*	macromolecules	Electrophoresls system	R. Snyder	NASA-GSFC, Greenbelt MY
3	*Helianthus annuus*	Plant	Sealed vials	A.H. Brown	UPA Philadelphia PA
4	*Apis mellifera*	Insect	Insect chamber	T.E. Nelson	Southland HS, Adams MN
5	*Musca domestica*	Insect	Insect chamber	T.E. Nelson	Southland HS, Adams MN
6		Insect	Insect chamber	T.E. Nelson	Southland HS, Adams MN
7	*Vigna radiata*	Plant	Plant growth unit (PGU)	J.R. Cowles	U Houston, Houston TX
8	*Avena sativa*	Plant	Plant Growth Unit (PGU)	J.R. Cowles	U Houston, Houston TX
9	*Pinus elliotti*	Plant	Plant growth unit (PGU)	J.R. Cowles	U Houston, Houston TX
10	*Chlorella vulgaris*	Algae, free living	Algae growth chamber	S.M. Walker	Utah State U, Logan UT
11	*Lemna minor*	Plant	Plexiglas growth chamber	K.D. Hunt	Utah State U, Logan UT
12	*Artemia salina*	Invertebrate	Sealed aquatic chamber	B. Moore	Utah State U, Logan UT
13	*Drosophila melanogaster*	Insect	Plexiglas growth chamber	W.M. Moore	Utah State U, Logan UT
14	*n.a.*	macromolecules	FFE system	D. Clifford	McDonnell Douglas
15	*Microciona porifera*	Invertebrate	Aquarium (2 sections)	A.K. Gillette	Winter Haven HS, Winter Haven FL
16	*n.a.*	macromolecules	FFE system	D. Clifford	McDonnell Douglas
17	*unspecified*	Bacteria, free living	GAS canister	K.R. Shriner	USAF Academy, Colorado Springs CO
18	*various*	Plant	Dacron/Plastic Bags	G.B. Park	Park Seed Co, Greenwood SC
19	*n.a.*	macromolecules	FFE system	D. Clifford	McDonnell Douglas

20	*unspecified*	Plant	Seed containers	M. Buchwald	German Youth Fair Program (Jufo)
21		Plant		H. Katzenmeire	German Youth Fair Program (Jufo)
22	*Helianthus sp.*	Plant	Rotating drum	Students	Purdue U, West Lafayette IN
23	*Myrmica sp.*	Insect	Wooden ant farm	Students	Camdery W. Wilson HS, Camden NJ
24	*Raphanus sativus*	Plant	Multiplatter centrifuge	Students	California Institute of Technology, CA
25	*n.a.*	macromolecules	FFE system	D. Clifford	McDonnell Douglas
26	*Artemia salina*	Invertebrate	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
27	*Bacillus subtilis*	Bacterial spores	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
28	*Nicotiana tabacum*	Plant	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
29	*Arabidopsis thaliana*	Plant	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
30	*Sordaria fimicola*	Fungus spores	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
31	*Bacillus subtilis*	Bacterial spores	Open exposure on pallet	G. Horneck	DLR Cologne (DFVLR)
32	*Homo sapiens sapiens*	Lymphocytes		A. Cogoli	ETH Zürich
33	*Neurospora crassa*	Fungus	Culture tubes (dark)	F.M. Sulzman	State U of New York, Binghamton NY
34	*Helianthus annuus*	Plant	Videotape recording under IR	A.H. Brown	UPA, Philadelphia PA
35	*n.a.*	macromolecules	Electrophoresis system		Utah State U, Logan UT
36	*Raphanus sativus*	Plant	Plexiglas growth chamber	Students	Brighton HS, Salt Lake City UT
37	*n.a.*	macromolecules	Electrophoresis system	M. Bler	University of Arizona Tucson AZ
38	*Rattus rattus*	Mammal	Animal enclosure module (AEM)	D. Weber	Hunter College HS, New York NY
39	*Apis mellifera*	Insect	Bee enclosed module (BEM)	D.M. Poskevich	Waverty Central HS, Waverly TN
40	*Artemia salina*	Invertebrate	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
41	*Bacillus subtilis*	Bacterial spores	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
42	*Nicotiana tabacum*	Plant	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
43	*Arabidopsis thaliana*	Plant	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
44	*Zea mays*	Plant	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
45	*Sordaria fimicola*	Fungus spores	HZE tracking sandwich	H. Buecker	DLR Cologne (DFVLR)
46		Plant	Seed containers	D.K. Grigsby	Park Seed Co, Greenwood SC

47	*various*	Plant	Seed containers	G.B. Park	Park Seed Co, Greenwood SC
48	*n.a.*	macromolecules	FFE system	D. Clifford	McDonnell Douglas
49	*Raphanus sativus*	Plant		G.A. Smith	UAH, Huntsville AL
50	*n.a.*	macromolecules	FFE System	D. Clifford	McDonnell Douglas
51	*n.a.*	macromolecules		D.E. Brookes	University H & S Oregon
52	*Zea mays*	Plant		S.M. Amberg	Seward HS, Seward NE
53	*Musca domestica*	Insect	Fly enclosure module (FEM)	A.I. Fras	Binghamton HS, Binghamton NY
54	*Saimiri sciureus*	Mammal	*Research animal holding facility*	C. Schatte	NASA-ARC, Moffet Field CA
55	*Rattus rattus*	Mammal	*Research animal holding facility*	C. Schatte	NASA-ARC, Moffet Field CA
56	*Rattus rattus*	Mammal	*Research animal holding facility*	C. Schatte	NASA-ARC, Moffet Field CA
57	*unspecified*	Bacteria, free living	Agar cultures	K. Herman	EI Paso/Ysleta Schools, EI Paso TX
58	*Artemia salina*	Invertebrate	Hatching chamber	D.R. Cake	EI Paso/Ysleta Schools, EI Paso TX
59	*Mucor rouxii*	Fungus, free living	Plexiglas chambers	R. Lopez	EI Paso/Ysleta Schools, EI Paso TX
60	*Lactuca sativa*	Plant		D. Bowden	EI Paso/Ysleta Schools, EI Paso TX
61		Plant	Wet paper towels	P. Campos	EI Paso/Ysleta Schools, EI Paso TX
62	*Hordeum vulgare*	Plant		G. Bryant	EI Paso/Ysleta Schools, EI Paso TX
63	*Chlorella sp.*	Algae, free living		R. Santini	EI Paso/Ysleta Schools, EI Paso TX
64	*Kefir sp.*	Fungus, free living		R. Santini	EI Paso/Ysleta Schools, EI Paso TX
65	*Dugesia tigrina*	Invertebrate	Growth chamber	M. Chavez	EI Paso/Ysleta Schools, EI Paso TX
66	*Vigna radiata*	Plant	Plant growth unit (PGU)	J.R. Cowles	U Houston, Houston TX
67	*Avena sativa*	Plant	Plant growth unit (PGU)	J.R. Cowles	U Houston, Houston TX
68	*Pinus elliotti*	Plant	Plant growth unit (PGU)	J.R. Cowles	U Houston, Houston TX
69	*Escherichia coli*	Bacteria, free living	Biorack	O. Cifferi	University Pavia
70	*Phage K1*	Bacteriophage, free living	Biorack	O. Cifferi	University Pavia
71	*Drosophila melanogaster*	Insect	Biorack	R. Marco	Universidad Autonoma Madrid
72	*Physarum polycephalum*	Slime mould, free living	Biorack	V. Sobick	DLR Cologne (DFVLR)
73	*Carausius morosus*	Insect	Biorack	H. Buecker	DLR Cologne (DFVLR)
74	*n.a.*	Dosimeters	Biorack	H. Buecker	DLR Cologne (DFVLR)
75	*Paramecium caudatum*	Protozoa, free living	Biorack	H. Planel	National Institute of Health, Toulouse
76	*Paramecium caudatum*	Protozoa, free living	Biorack	H. Planel	National Institute of Health, Toulouse

77	*Chlamydomonas reinhardii*	Algae, free living	Biorack	D. Mergenhagen	University Hamburg
78	*Bacillus subtilis*	Bacteria, free living	Biorack	H.D. Mennigmann	University Frankfurt
79	*Homo sapiens sapiens*	Lymphocytes	Biorack	A. Cogoli	ETH Zürich
80	*Homo sapiens sapiens*	Lymphocytes	Biorack	A. Cogoli	ETH Zürich
81	*Lens culinaris*	Plant	Biorack	G. Perbal	University Curie Paris
82		Lymphocytes	Biorack	M. Bouteille	University Paris
83	*Xenopus laevis*	Amphibia	Biorack	G.A. Ubbels	Hubrecht Laboratory Utrecht
84	*Escherichia coli*	Bacteria, free living	Biorack	R. Tixador	National Institute of Health, Toulouse
85	*Lepidium sativum*	Plant	NEXPA facility	D. Volkmann	University Bonn
86	*Zea mays*	Plant	NEXPA facility	J. Gross	University Tübingen
87	*Pimpinella anisum*	Plant Cells	NEXPA facility	R.R. Thelmer	University Münich
88	*Xenopus laevis*	Amphibian	NEXPA facility	J. Neubert	DLR Cologne (DFVLR)
89	*n.a.*	macromolecules	FFE system	D. Clifford	McDonnell Douglas
90	*Amaranthus hypocondriacae*	Plant		A.J.V. Peluyera	Instituto del Consumidor, Mexico City
91	*Lens esculenta*	Plant		A.J.V. Peluyera	Instituto del Consumidor, Mexico City
92	*Triticum aestivum*	Plant		A.J.V. Peluyera	Instituto del Consumidor, Mexico City
93	*Escherichia coli*	Bacteria, free living		S.E. Flores	University Center, Mexico City
94	*Phage lambda CII-68*	Bacteriophage, free living		S.E. Flores	University Center, Mexico City
95	*Phaseolus vulgaris*	Plant		I. Ortega	Laboratoria de Cuernavaca
96	*Zea mays*	Plant		C.L. Wang	Richfield HS, Waco TX
97	*Raphanus sativus*	Plant		G.A. Smith	UAH, Huntsville AL
98	*Artemia salina*	Invertebrate	Growth chamber	A. White	B.T. Washington HS Houston TX
99	*Lymantria dispar*	Insect	Nylon mesh on cotton screen	D.K. Hayes	USDA, Beltsville MD
100	*Dermacentor variabilis*	Insect	Nylon mesh on cotton screen	D.K. Hayes	USDA, Beltsville MD
101	*n.a.*	macromolecules	Liquid chromatography system		Alitech Associates Inc.
102	*n.a.*	macromolecules	Electrophoresis system	M. Bier	University of Arizona, Tucson AZ
103	*n.a.*	macromolecules		D.E. Brooks	U of British Columbia, Vancouver
104	*Haplopappus gracilis*	Plant	Plant growth unit (PGU)	A.D. Krikorian	State U of New York, Stony Brook NY

105		Plant	Plant growth unit (PGU)	A.D. Krikorian	State U of New York, Stony Brook NY
106	*Rattus rattus*	Mammal		A.I. Fras	Binghamton HS, Binghamton NY
107	*Gallus domesticus*	Bird	Incubator box	J.C. Vellinger	Jefferson HS, Lafayette IN
108	*Zea mays*	Plant	Plant canisters + N2 freezer	R. Bandursid	University of Michigan
109	*Neurospora sp.*	Fungus		J.S. Ferraro	Southern Illinois U, Carbondale IL
110		Plant	Plant growth unit (PGU)	A.D. Krikorian	State U of New York, Stony Brook NY
111	*Rattus rattus*	Mammal	Animal enclosure modules (AEM)	M. Cornin	CCDS-PSU (CCR) / Genentech, CA
112	*various*	various	Materials dispersion app. (MDA)	M. Luttgee	CCDS-UCO, Boulder CO (Bioserce)
113	*Rattus rattus*	Mammal	RAHF or AEM	K.M. Baldwin	U of California, Irvine CA
114	*Rattus rattus*	Mammal	RAHF or AEM	E.R. Morey-Holton	NASA-ARC, Moffett Field CA
115	*Rattus rattus*	Mammal	RAHF or AEM	J. Foon Yoong Hoh	NASA-ARC/University of Sydney
116	*Rattus rattus*	Mammal	RAHF or AEM	D.A. Riley	Medical College of Wisc., Milwaukee WI
117	*Rattus rattus*	Mammal	RAHF or AEM	C. Altrey	Baylor College of Medicine, Houston TX
118	*Rattus rattus*	Mammal	RAHF or AEM	R.D. Lange	U of Tennessee, Knoxville TN
119	*Rattus rattus*	Mammal	RAHF or AEM	M. Ross	NASA-ARC, Moffett Field CA
120	*Aurelia aurita*	Invertebrate		D.B. Spangenberg	E. Virginia Medical School, Norfolk VA
121	*Homo sapiens sapiens*	Lymphocytes		A. Cogoli	ETH Zürich
122	*various*	Plant			Nissho Iwai American Corp., NY
123	*various*	Plant			Sakana Seeds Corp., Yokohama
124	*various*	various	Materials dispersion app. (MDA)	M. Luttges	CCDS-UCO, Boulder CO (Bioserve)
125	*Rattus rattus*	Mammal	Animal enclosure modules (AEM)	M. Tischler	University of Arizona, Tucson AZ
126	*none*	n.a.	STLV bioreactor	G. Spaulding	NASA-JSC, Houston TX
127		Mammal bone cells	Biorack	J.P. Veldhujzen	Free University Amsterdam
128	*Xenopus laevis*	Amphibia	Biorack	G.A. Ubbells	Hubrecht Laboratory Utrecht
129	*Drosophila melanogaster*	Insect	Biorack	R. Marco	Universidad Autonoma Madrid
130	*Daucus carota*	Plant Cells	Biorack	O. Rasmussen	University of Aarhus
131	*Brassica napus*	Plant cells	Biorack	O. Rasmussen	University of Aarhus
132	*Carausius morosus*	Insect	Biorack	H. Bueker	DLR Cologne
133	*none*	n.a.	Biorack	G. Reltz	DLR Cologne

134	*Bacillus subtilis*	Bacteria, free living	Biorack	H.D. Mennigmann	University Frankfurt
135	*Bacillus subtilis*	Bacteria spores	HZE tracking sandwich	H. Buecker	DLR Cologne
136	*Saccharomyces cerevisiae*	Fungus spores	HZE tracking sandwich	H. Buecker	DLR Cologne
137	*Sordaria fimicola*	Fungus spores	HZE tracking sandwich	H. Buecker	DLR Cologne
138	*Artemia salina*	Invertebrate	HZE tracking sandwich	H. Buecker	DLR Cologne
139	*Arabidopsis thaliana*	Plant	HZE tracking sandwich	H. Buecker	DLR Cologne
140	*Homo sapiens sapiens*	Erythrocytes	Biorack	A. Cogoli	ETH Zürich
141	*Homo sapiens sapiens*	Lymphocytes	Biorack	A. Cogoli	ETH Zürich
142		Kidney cells	Biorack	A. Cogoli	ETH Zürich
143	*Arabidopsis thalliana*	Plant	Biorack	L.G. Briarty	University of Nottingham, UK
144	*Bacillus subtilis*	Bacteria, spores	HZE tracking sandwich	S. Nagasaki	NASDA, Tokyo
145	*Artemia salina*	Invertebrate	HZE tracking sandwich	S. Nagasaki	NASDA, Tokyo
146	*Zea mays*	Plant	HZE tracking sandwich	S. Nagasaki	NASDA, Tokyo
147	*Lens culinaris*	Plant	Biorack	G. Perbal	Curie University Paris
148	*Physarum polycephalum*	Slime mould, free living	Biorack	I. Block	DLR Cologne
149	*Escherichia coll*	Bacteria, free living	Biorack	R. Tixador	National Institute of Health, Toulouse
150	*Triticum aestivum*	Plant	Gravit. Plant Physical Facility (GPPF)	D.G. Heathcote	UPA Philadelphia PA
151	*Avena sativa*	Plant	Gravit. Plant Physical Facility (GPPF)	A.H. Brown	UPA Philadelphia PA
152	*Caenorhabditi s elegans*	Invertebrate	Biorack	G.A. Nelson	NASA-JPL, Pasadena CA
153	*Saccharomyces cerevisiae*	Fungus, free living	Biorack	C.V. Bruschl	L. Berkeley Laboratory, Berkeley CA
154		Mammal limb cells	Biorack	P.J. Duke	University of Texas, Houston TX
155	*n.a.*	macromolecules		D.E Brools	U of British Columbia, Vancouver
156	*Artemia salina*	Invertebrate			B.T. Washington HS, Houston TX
157	*Rattus rattus*	Mammal Cells	Automated tray assembly	E.R. Morey-Holton	NASA-ARC, Moffett Field CA
158	*none*	n.a.	Plant growth system (LT)	T.W. Tibbitts	CCDS-UWI Madison WI (WCSAR)
159	*various*	various	Fluid processing apparatus (FPA)	M.C. Robinson	CCDS-UCO, Boulder CO (Bioserve)

160	*Rattus rattus*	Mammal brain gland cells	Middeck incubator	M.C. Hymer	PA State U, University Park PA
161	*Aspergillus niger*	Fungus, spores	Open exposure on pallet	K. Dose	University Mainz
162	*Aspergillus ochraceus*	Fungus, spores	Open exposure on pallet	K. Dose	University Mainz
163	*Saccharomyces cerevisiae*	Fungus, spores	Open exposure on pallet	J. Kiefer	University Giessen
164	*Bacillus subtilis*	Bacteria, spores	Open exposure on pallet	G. Horneck	DLR Cologne
165	*Deinococcus radiodurans*	Bacteria, spores	Open exposure on pallet	G. Horneck	DLR Cologne
166	*Ditylenchus dipsacii*	Invertebrate	Open exposure on pallet	G. Horneck	DLR Cologne
167	*Neurospora crassa*	Fungus		Y. Miyoshi	Tokyo University
168		Fish	Aquarium (VFEU)	S. Mori	Nagoya University
169	*n.a.*	Macromolecules	Free flow electrophoresis	M. Kuroda	Osaka University
170		Mammal kidney cells		A. Sato	Tokyo Medical and Dental University
171	*Homo sapiens sapiens*	Lymphocytes		H. Ooka	Tokyo university
172		Plant Cells	Culture chambers (semi-solid agar)	Y. Yamada	Tokyo University
173	*Gallus domesticus*	Bird	Egg holding rack	T. Suda	Showa University
174	*Salmonella typhimurium*	Bacteria, free living	Free flow electrophoresis	T. Yamaguchi	Tokyo Medical and Dental University
175	*Drosophila melanogaster*	Insect	Fly containers	M. Ikenaga	Tokyo University
176	*Zea mays*	Plant	HZE tracking sandwich	S. Nagaoka	NASDA, Tokyo
177	*Bacillus subtilis*	Bacteria, spores	HZE tracking sandwich	S. Nagaoka	NASDA, Tokyo
178	*Artemia salina*	Invertebrate	HZE tracking sandwich	S. Nagaoka	NASDA, Tokyo
179	*Xenopus laevis*	Amphibia	Frog environment unit	K.A. Souza	NASA-ARC Moffett Field CA
180	*Xenopus laevis*	Amphibia	Frog environment unit	K.A. Souza	NASA-ARC Moffett Field CA
181	*Daucus carota*	Plant cells	Culture chambers (semi-solid agar)	A.D. Krikorian	State U of New York, Stony Brook NY
182		Plant cells	Culture chambers (semi-solid agar)	A.D. Krikorian	State U of New York, Stony Brook NY
183		Mammal osteoblast cells		N. Partridge	St. Louis U Medical School, St Louis MO
184	*Vespa orientalis*	Insect	Normal containers	J.S. Ishey	Tel Aviv University
185				Students	Kansas U, Lawrence KS
186		Plant			Kansas U, Lawrence KS

187	*various*	Various	Material dispersion apparatus (MDA)	M. Lewis	CCDS-UAH, Huntsville AL (CMDS)
188	*n.a.*	macromolecules		D.E. Brooks	U of British Columbia, Vancouver
189	*Rattus rattus*	Mammal	Animal enclosure modules (AEM)	G. Rodan	CCDS-UCO (Bioserve)/Merck Inc
190	*none*	n.a.	ASPEC bioreactor	G. Spaulding	Medical Sciences Div, NASA-JSC
191	*various*	various	Fluid processing apparatus (FPA)	M. Luttges	CCDS-UCO, Boulder CO (Bioserve)
192	*Arabidopsis thaliana*	Plant	Plant growth unit (PGU)	M. Musgrave	Louisiana State University
193	*Rattus rattus*	Mammal	Animal enclosure modules (AEM)	K.M. Baldwin	U of California, Irvine CA
194	*Xenopus laevis*	Amphibia	Biolabor	E. Horn	University Ulm
195	*Oreochromis mossambicus*	Fish	Biolabor	E. Horn	University Ulm
196	*Xenopus laevis*	Amphibia	Biolabor	J. Neubert	DLR Cologne
197	*Oreochromis mossambicus*	Fish	Biolabor	J. Neubert	DLR Cologne
198	*Xenopus laevis*	Amphibia	Biolabor	H. Rahmann	University of Stuttgart
199	*Oreochromis mossambicus*	Fish	Biolabor	H. Rahmann	University of Stuttgart
200	*Xenopus laevis*	Amphibia	Biolabor	M. Schachner	University Heidelberg
201	*Oreochromis mossambicus*	Fish	Biolabor	M. Schachner	University Heidelberg
202	*Lepidium sativum*	Plant	Biolabor	D. Volkmann	University Karlsruhe
203	*Lepidium sativum*	Plant	Biolabor	M.H. Welsenaeel	University Karlsruhe
204	*Flammulina velutipes*	Fungus	Biolabor	B. Hock	Technical University Münich
205	*Panax ginseng*	Plant cells	Biolabor	H. Jung-Hellger	Plant Laboratory Cells
206	*Saccharomyces uvarum*	Fungus, free living	Biolabor	S. Donhauser	Technical University Münich
207	*Escherichia coli*	Bacteria, free living	Biolabor	H.D. Mennigmann	University Frankfurt
208	*Bacillus subtilis*	Bacteria, free living	Biolabor	H.D. Mennigmann	University Frankfurt
209	*Escherichia coli*	Bacteria, free living	Biolabor	H.D. Mennigmann	University Frankfurt
210	*Bacillus subtilis*	Bacteria, free living	Biolabor	H.D. Mennigmann	University Frankfurt
211	*Homo sapiens sapiens*	Skin fibroblasts	Biolabor	P.K. Mueller	University Lubeck
212	*Homo sapiens sapiens*	T-lymphocytes	Biolabor	K. Reske	University Mainz
213	*Homo sapiens sapiens*	T-lymphocytes	Biolabor	K. Reske	University Mainz
214	*Homo sapiens*	B-lymphocytes	Biolabor	U. Zimmermann	University Wurzburg

	sapiens		electrofusion		
215	*Nicotiana tabacum*	Plant cells	Biolabor electrofusion	R. Hampp	University Tübingen
216	*Digitalis sp.*	Plant cells	Biolabor electrofusion	R. Hampp	University Tübingen
217	*Helianthus sp.*	Plant Cells	Biolabor electrofusion	R. Hampp	University Tübingen
218	*Artemia salina*	Invertebrate	Biostack HZE tracking sandwich	H. Buecker	DLR Cologne
219	*Arabidopsis thaliana*	Plant	Biostack HZE tracking sandwich	H. Buecker	DLR Cologne
220	*Sordaria fimicola*	Fungus, spores	Biostack HZE tracking sandwich	H. Buecker	DLR Cologne
221	*Bacillus subtilis*	Bacteria, spores	Biostack HZE tracking sandwich	H. Buecker	DLR Cologne
222	*Saccharomyces cerevisiae*	Fungus, spores	Biostack HZE tracking sandwich	H. Buecker	DLR Cologne
223	*Bacillus subtilis*	Bacteria, spores	Open exposure on pallet	G. Horneck	DLR Cologne
224	*Haemophilus influenzae*	Bacterial isolated DNA	Open exposure on pallet	G. Horneck	DLR Cologne
225	*various*	various	Bioprocessing modules (BPM)	M. Lewis	CCDS-UAH, Huntsville AL (CMDS)
226	*various*	various	Materials Dispersion App. (MDA)	M. Lewis	CCDS-UAH, Huntsville AL (CMDS)
227	*Rattus rattus*	Mammal	Animal enclosure modules (AEM)	E.R. Morey-Holton	NASA-ARC, Mountain View CA
228	*Rattus rattus*	Mammal muscle and bone cells	Automated tray assembly	E.R. Morey-Holton	NASA-ARC, Mountain View CA
229	*none*	n.a.	Plant growth system (LT)	R.J. Bula	CCDS-UWI, Madison WI (WCSAR)
230	*Rhizobium trifolii*	Symbiotic bacteria	Bioprocessing modules (BPM)	M. Luttges	CCDS-UCO, Boulder CO (Bioserve)
231	*Escherichia coli*	Bacteria, free living	Bioprocessing modules (BPM)	M. Luttges	CCDS-UCO, Boulder CO (Bioserve)
232		Amphibian kidney cells	Bioprocessing modules (BPM)	M. Luttges	CCDS-UCO, Boulder CO (Bioserve)
233	*various*	various	Fluid processing apparatus (FPA)	M. Luttges	CCDS-UCO, Boulder CO (Bioserve)
234	*n.a.*	macromolecules	Organic separation device	J.M. Van Aistine	CCDS-UAH, Huntsville AL (CMDS)
235	*Rattus rattus*	Mammal	Animal enclosure modules (AEM)	G. Rodan	CCDS-PSU (CCR)/Space Dermat Fnd
236		Mammal colon cells	ASPEC bioreactor	G. Spaulding	Medical Sciences Div. , NASA-JSC
237		Plant		Students	California Central Coast Schools
238		Bacteria		Students	California Central Coast Schools
239		Bacteria		Students	California Central Coast Schools
240		Plant		Students	California Central Coast Schools

241	*Arabidopsis thaliana*	Plant	Plant growth unit (PGU)	M. Musgrave	Louisiana Stare University
242	*Triticum aestivum*	Plant	Plant growth unit (PGU)	A.D. Krikorian	State U of New York, Stony Brook NY
243	*Triticum aestivum*	Plant	Plant growth unit (PGU)	N. Lewis	Washington State University

8.15.1 U.S.A.

In his address to the U.S. House of Representatives Task Force on Defence, Foreign Policy, and Space, in April 1992, Professor R.H. Moser, on behalf of the National Research Council, U.S. National Academy of Sciences, made this opening statement: ‘Exploring the effects of microgravity on the development and maintenance of living systems is of considerable scientific interest. It is imperative, however, that national goals guide a research endeavour of this magnitude. Purely academic curiosity is an insufficient rationale for investing tax dollars on this scale.’ He went on to comment that ‘... the primary justification for space life sciences research is a commitment to long-term human exploration.’

The NASA long-term strategy for life sciences research appears to reflect this viewpoint, up to a certain level. There is indeed a strong emphasis on the human life sciences research and on those research areas in biology which would appear to support the overall development of the human space life sciences programmes. There is also, however, a commitment to basic research, a willingness to allow for ‘academic curiosity’ and the study of effects down to the most basic level, where these appear to have serious merit as judged by the scientific review process.

Reflecting the official position and emphasis, the NRC Space Studies Board, in their *Space Exploration Initiative* document, presented the following ‘order of priority’ list for the general research fields in the human life sciences, as far as their importance for future extended space travel is concerned: bone, muscle, and mineral metabolism research; the study of cardiovascular and homeostatic functions; sensorimotor integration processes; psychosocial perturbations and radiation exposure effects.

This, of course, seems to do no more than indicate the likely relative importance of the different processes in reducing the probability of success of an extended space mission, although some might query the relative importance accorded to the radiation effects. Certainly, it is not reflected in the actual distribution of U.S. experiments on the Shuttle for the different research fields. Fig. 3 illustrates that distribution, the data being taken from the information in Table 14.

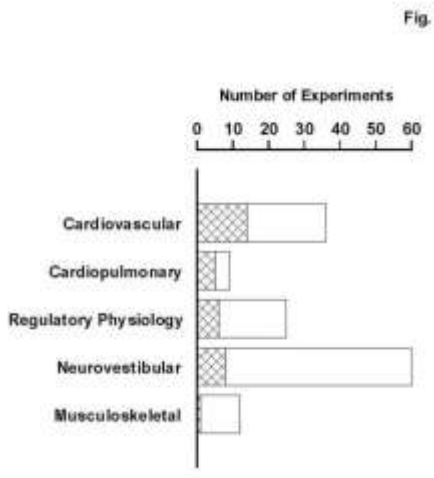

Fig. 3. Human life science experiments performed in each research category on STS missions 1981-1993. Experiments with European Principal Investigators are shown with cross-hatched shading.

Evidently, the principal concerns of NASA up to the present time, where most flights - excluding the Skylab mission - have been of short duration, has been with the space sickness and disorientation effects which disturb efficiency during the first few days. With the progress towards longer term missions, on Mir and the International Space Station that emphasis will presumably change.

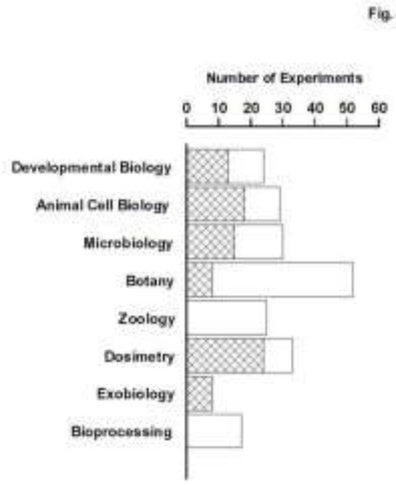

Fig. 4. Biological research experiments performed in each research category on STS missions 1981-1993. Experiments with European Principal Investigators are shown with cross-hatched shading.

The NASA Space Biology programme, operated principally by the NASA Ames establishment, was established across the three main areas of *Gravity Perception*, in animals and plants, *Developmental Biology*, and *Biological Adaptation* - where gravity is used as a variable to examine its effects on organisms and cells. The programme has relied not only upon the Shuttle based experiments, but also upon the opportunities offered by the collaboration with the USSR/Russia in the Biocosmos recoverable satellite series. Fig. 4 shows the relative distribution of U.S. Shuttle based experiments (and European experiments) across the different research disciplines in space biology. The apparently small number of U.S. experiments performed in dosimetry is not a true reflection of the NASA interest in this field since measurements are carried out under other NASA programmes.

Fig. 5 illustrates the distribution, by research discipline, of U.S. experiments carried out on the Russian Biocosmos recoverable spacecraft. Initially, these experiments were in the form of ‘carry-on’ packages, requiring no spacecraft services. The more recent experiments, considered here (Bion 6 - 10), were U.S. battery operated instruments, which were integrated into the Russian spacecraft data systems. U.S. experiments were also performed on the rhesus monkeys and rats housed in the Russian animal habitat. The distribution of U.S. research experiments across the disciplines contrasts markedly with the ESA Bion experiments, which were predominantly concerned with dosimetry and cell biology. Concentration on regulatory physiology and musculo-skeletal studies in these missions appears to reflect NASA’s primary interests.

Future space research in the life sciences at NASA will be directed increasingly towards exploiting the extended Mir space station following the addition of SPEKTR and PRIRODA modules in 1995. These have been designated by NASA as predominantly for life sciences research, as far as U.S. utilization is concerned. Planning for their outfitting by NASA is presently being carried out. Shuttle, Spacelab and Spacehab flights have been changed accordingly.

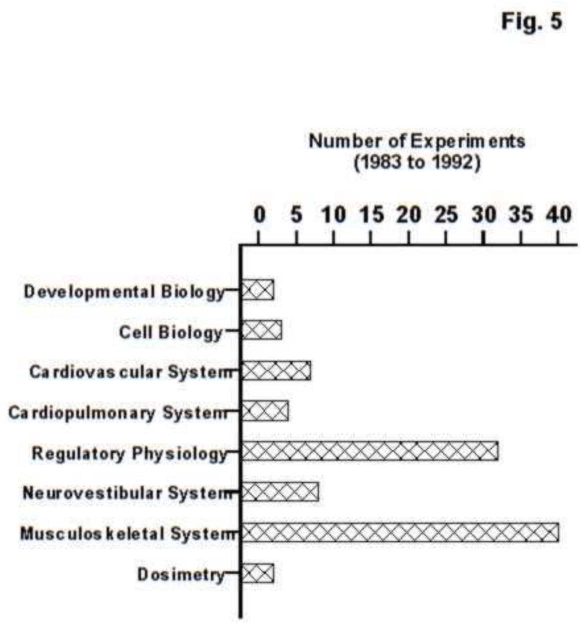

Fig. 5. U.S. life science experiments carried out on the Russian Biocosmos space craft (Bion 6 to 10).

Of the 4 independent Spacelab missions remaining in the NASA manifest, only the Neurolab (SLS-4) scheduled for 1997/8 offers a major life sciences mission. The emphasis will be on neurophysiology and it is expected that NASA will be able to make a significant contribution to the experiment hardware. The SL-M mission of May 1995 will be the first NASA Shuttle/Spacelab mission to the Mir complex, where it will be docked for 4 days. The principal emphasis of this mission is for logistics supply to Mir, but some science research is expected to be carried out with the Spacelab/Mir facilities. Subsequent missions to Mir carrying the Spacelab Long Module may have up to 30% of the resources allocated for scientific research. As yet this is no indication as to the likely type of payloads. Due to the very tight schedule for these Shuttle missions to Mir in the 1995-1997 period, coupled with the effects due to the high inclination orbit complicating the rendezvous and limiting severely the launch window each day, there is presently some consideration being given to reducing the number of missions. A limit of 6 may finally result.

Planning for the extension and use of the Mir Space Station is now developing within NASA. The science programme is intended to be conducted in collaboration with Russian scientists. To assist that process, common E.S.-Russian databases and procedures we be developed. The Russian crew will be trained to use the U.S. hardware and experiments, so that experimentation can be continued in the absence of U.S. crew. Where possible, NASA will utilize existing Russian Mir science hardware (e.g.) plant growth chambers, but it progressively improve the monitoring capabilities, resources and resource utilization.

Over sixty items of experimental hardware have been identified by NASA to be provided to extend the Mir research capabilities. These include: hygiene, sanitation, and radiation monitoring equipment (water and air sampling devices, tissue equivalent proportional counter); Metabolic experiments equipment (blood, wine, saliva collection kits, centrifuge); cardiovascular/ cardiopulmonary experiment equipment (barocuff, continuous blood pressure measurement device, metabolic gas analyzer); sensorimotor and neuromuscular function and exercise equipment; behaviour and performance measuring equipment; fundamental biology research equipment (fixative kits).

The general research programmes to be undertaken on Mir as its capabilities are upgraded are outlined in the following Sections.

8.15.1.1 Outline of U.S. research plans in the life sciences for the Mir extension

Biomedical studies of the consequences of long-duration space flight. Studies of the basic mechanisms by which respiration and blood are controlled in healthy individuals on Earth and in microgravity. Studies of fundamental control mechanisms of balance and coordination. Studies of mechanism of maintaining muscle strength and contractility and mechanism of maintaining bone mass and strength. Capacity to perform skilled tasks in microgravity. Drug absorption and action in microgravity. Medical measures to prevent the undesirable effects of microgravity. Evaluate the absorption and utilization of food energy during prolonged exposure to microgravity.

Fundamental biology investigations. Study of plant life cycle seed to seed to seed. Studies in developmental biology to evaluate how gravity affects organism from fertilization through maturity to aging. Cell structure to evaluate the specific effects of gravity on cells important to biomedical studies and biotechnology.

Metabolism studies. Standardization of protocols for joint experiments. Minimize the total and daily blood volume to be collected from the crew. Define the time and volume of blood to be collected during each flight phase based on the known physiologic changes that occur during the various phases of space flight. Reduce the crew time needed for conducting experiments on Mir (experiment on regulatory mechanisms, metabolic and energy maintenance, pharmacokinetic changes and immunology).

Cardiovascular and pulmonary system experiments. Development of a standard for comparability of hardware and software for data processing, analysis and presentation. US and Russian agreement on scientific content and procedures outlined in the experiment document. Identification of essential hardware for investigations. Specialist have agreed upon a list of in-flight hardware and ground equipment to support joint investigations (experiments: orthostatic tolerance, study of tolerance to physical, physiological responses during descent in the Shuttle).

Sensori-motor and neuromuscular function and exercise experiments. Science required to investigate sensorimotor function must include vestibular, visual-vestibular, and postural protocols to avoid misrepresentation of data and enhance understanding of human spatial orientation. Performance of neuromuscular protocols will add in a synergistic fashion to the sensorimotor protocols, reducing errors of interpretation. No in flight sensorimotor or neuromuscular investigations are currently possible without US-provided hardware (experiments : neuromuscular, sensorimotor - active and passive).

Hygiene, sanitation, and radiation monitoring. Focus on dynamic human-environment interactions during long-term space flight, on characterization of the radiation environment, and on biological effects of radiation exposure. Studies will include joint analysis of samples of air and regenerated water, crew microbial biota, microbiota of spacecraft materials and hardware. Studies will be conducted on cytogenetic effects of radiation exposures and joint measurement of the spacecraft's internal radiation environment. Ground-based comparison studies will be conducted with US and Russian microbial and trace chemical air samplers and microbial samplers to facilitate interpretation of flight experiments. US and Russian scientists will work together to develop in flight procedures and equipment for microbial water monitoring (experiments: microbiology, radiological health, traces chemical contamination).

Behaviour and performance studies. Pre-flight psychological preparation and training crew members. In flight monitoring of crew member's psychological condition. In flight provision of psychological support to crew members (experiments: psychological dynamics and efficiency to countermeasures during extended space flight, effectiveness of manual control during simulation of flight tasks).

Fundamental biology research. Study of ontogenesis, including embryogenesis, and reproductive capability of Japanese quail during space flight. Study of complete ontogenic cycle of higher plants during space flight (experiment ‘Seed to seed’). Study of photosynthesis of higher plants during space flight. U.S. and Russian representatives agree on the need for more post-flight studies of biological materials received on Earth following the investigations during Mir-Shuttle mission (experiments: incubator, greenhouse).

Biotechnology experiments. Electrophoresis experiments, using Russian hardware initially. Cell culture, using the U.S. developed Bioreactor. Gaseous nitrogen freezer equipment provided, for sample storage and return.

As mentioned earlier, NASA has reached an agreement with the RKA to take a major share of the resources offered by the two modules SPEKTR and PRIRODA, due to be launched to Mir in 1995, and to dedicate these to the life sciences. The SPEKTR will accommodate about 1000 kg and PRIRODA 840 kg of useful payload for this purpose, primarily for human physiology experiments. Much of this equipment will probably derive from that used earlier on the SLS-1 and SLS-2 Spacelab missions.

8.15.1.2 The U.S.-Russian co-operation agreement

According to this agreement, there will be three phases to the future developments. Phase 1 will start during 1995 when the two Russian experiment modules PRIRODA and SPEKTR will be launched and docked with the Mir-1 Space Station. NASA expects to use both of these modules, in cooperation with Russia, primarily for life sciences research. They will contain extensive crew exercise equipment and also accommodate EXPRESS racks, designed originally for the Space Station Freedom. These are intended for largely self-contained experiments, located in standard drawer units. Phase 1 also covers the Shuttle missions to Mir, in the time frame from 1995 to 1997. During this phase U.S. crews will be on Mir during mission numbers Mir 18A (March - June 1995), Mir 20B (March - May 1996), Mir 21 (May - October 1996), Mir 22 (November 1996 - April 1997), with a further flight, Mir 23 (April - August 1997), under discussion. In addition, there will be an international ESA crew on flight Mir 19 (August - December 1995, Euromir 95) and French astronauts will be part of the Mir 21 crew (Cassiopea mission).

Phase 1 will involve extending the orbital lifetime of Mir up to at least the end of 1997. One of the first objectives of Phase 1 is therefore to replace or improve some of the essential sub-systems of Mir, such as the life support system, the solar power generator and the altitude control system. NASA will provide up to 10 Shuttle missions to Mir-1 during this period (to the end of 1997). Five of these missions are scheduled to involve the Spacelab, with the first mission in May 1995.

Phase 2 of the U.S.-Russian co-operation agreement, will involve the assembly of a new Core Station, using a new upgraded Mir module, with improved power and control systems, and data handling facilities. Russia will first provide an Energy ‘Block’, serving for initial station attitude control and re-boost, together with a Service Module, similar to the Mir-1 pressurized module and containing basic housekeeping functions, life support, power and thermal control, and performing limited payload operations. Further flights will provide docking nodes (as seen in the Mir-1 configuration) as well as a solar array, including the truss structures. Finally, Phase 2 developments will be completed with the launch of the US Laboratory and its outfitting in the period 1997/1998. Phase 2 will be operated on a ‘man tended’ basis.

Phase 3, covering 1998-2002, will see the completion of the Space Station, followed by the progressive addition of elements derived from the international partners, Canada, Japan and ESA and the U.S. SpaceHab module, to provide a permanently inhabited Laboratory system, around 2002.

At the present time, the US/Russian planning for the utilization of the Station through Phase 2 and up to the addition of contributions from the other Partners, foresees only a US/Russian activity. This situation may well change however, as far as ESA is concerned. There are offers from NASA for ESA to contribute to the NASA outfitting programme, and to derive experimentation opportunities in return, during this period. The NASA approach to experiment hardware for the Station is seen to be undergoing a significant change. The original concept of facility structure, occupying double racks, is being replaced with a more flexible approach which is based upon the apparent success of the Mid-deck Locker type of independent experiment. The EXPRESS racks to be fitted into SPEKTR and PRIRODA are evidence of this change.

8.15.1.3 NASA life science research facilities for the International Space Station

Three major life science facilities are currently foreseen for the outfitting of the U.S. laboratory on the Station. These are the Centrifuge Facility, the Human Research Facility - for which the Johnson Space Center is now responsible, and the Gravitational Biology Facility, which is supported by the Ames Research Center.

The Gravitational Biology Facility will occupy two Station racks and contains the modules and items listed in Table 17. The purpose of this facility is to support the growth and development of a variety of specimens, including cell and tissue cultures, higher plants, insects, fish, avian embryos, and small mammals. It is also intended to allow basic specimen manipulation processes and analyses. The first of the two racks, containing the Bioculture system, plant research unit, and insect habitat, together with the temperature controlled chamber and slow freeze accessories, is intended for a 1998 launch to the Station. The second rack, containing the rest of the equipment would be on Station in 2000.

Table 17. Components of the Gravitational Biology Facility planned for the International Space Station

Integral to GBF development		Provided by other programmes	
Habitats	Multi-disciplinary items	Habitats	Multi-disciplinary items
Bio-culture system Plant research unit Insect habitat Aquatic habitat Avian egg incubator Rodent birthing & rearing habitat	Temperature controlled chamber Dissection equipment Slow freeze accessories Temperature controlled laboratory centrifuge Compound microscope	Large plant habitat (CFP)* Rodent breeding habitat (CFP) Rodent habitat (CFP)	Passive dosimeter (SS)* Quick/snap freezer (SS) -196^o C freezer (SS) Life sciences glovebox (CFP) Dissecting microscope (SS) Fluid handling tools (SS) -70^o C freezer (SS) Refrigerator (4^o C) (SS) -20^o C freezer (SS) Freeze dryer (SS) Mass measuring device (SS)

*CFP = Centrifuge Facility Project, SS = Space Station Programme

The Human Research Facility (HRF) has three basic objectives: to develop countermeasure procedures and protocols to maintain crew health and performance in space, to provide a basic research capability which is focused on earth based health problems, and to develop the capability to integrate human experiment data sets, from past, current, and future programmes.

The facility is likely to contain the following basic items: (i) automatic blood pressure system; (ii) core body temperature measurement system; (iii) experiment control computer system; (iv) echocardiographic/doppler blood flow; (v) carotid sinus baroreceptor stimulator.

The three phase programme for the development and deployment of the facility equipment (see Section 8.15.1.2) is correlated with the US/Russian flight schedule. During Phase 1, hardware will be located in the SPEKTR and PRIRODA modules, and also involve the STS-82 flight in 1996. Much of the scientific effort during this period will be directed towards the establishment of basic data sets relating to long term (90 day) space missions and the correlation with existing Russian data. Countermeasure procedures evaluation and the testing of prototype hardware will also take place.

During Phase 2, the objectives will be to continue Phase 1 efforts to develop science risk assessment protocols and countermeasure hardware and prescriptions for extended duration missions. Gather and analyze science and hardware data for use in future HRF phases and life sciences programmes. Assess Shuttle/Mir science and hardware data to enhance subsequent HRF phases. Establish acceptable levels of crew health and performance. Develop operational hardware that will occupy 0.8 rack in the US Lab.

The equipment rack to support Phase 2 will be launched in 1998, and will be accommodated in the U.S. Lab. Phase 3 of the HRF programme will be concerned with the development of countermeasures for missions of 180 days, or greater, and with a programme of basic human life sciences research. The hardware will occupy 2 Station racks, and be located in the U.S. Laboratory during 2000.

The Centrifuge Facility provides a variable gravity environment (0.01 to 2 $\times$ g) for research with plants and animals in the Station. The limit to animal size would be a small primate. The facility will include: centrifuge system; habitat holding system (1 - 2 racks); rodent and plant habitats; life sciences glovebox; specimen service system; rodent transporter.

The requirements placed upon the design of the centrifuge are to support a variety of experiments and specimen types for weeks to months (including multiple specimen types simultaneously with flexible accommodation growth; near identical conditions from microgravity to 2 $\times$ g, with multiple gravitational levels simultaneously and precisely controllable environments; access to specimens while maintaining bioisolation and biocontainment, able to accommodate hazardous materials and isolate disturbances from the Space Station.

The accommodation requirements for experimental organisms which are to be met by the facilities are as follows.

- For *mice and rats:* group or single housing; temperature range 18 to 27^{o}C (to within 1^{o}); relative humidity range 40 to 70%; controllable light cycle; light and dark cycle video; food and water available continuously.
- For *plants*: one large (1300 cm^2) or three small growing area(s) per habitat; growing height to 35 cm; temperature range 15 to 30^{o}C (to within 1^{o}); relative humidity range 40 to 80% (to within 10%); CO_2 controlled within the range 300 to 2000 ppm with an accuracy of 10 to 50 ppm; nutrient solution to have controllable pH and conductivity; controllable light cycle levels with light and dark cycle video.

The Holding Unit and the Habitats are expected to be launched in 2002, with the Centrifuge itself following in 2004. The current launch schedule for the Life Science Facilities is shown in Tables 18 and 19.

Table 18. Current launch manifest for NASA life sciences facilities

Science discipline	Payload	1998	1999	2000	2001	2002	2003	2004
Life and biomedical sciences and applications	Gravitational biology facility	1*	1	2*	2	2	2	2
	Human research facility	0.8*	0.8	2*	2	2	2	2
	Habitat holding system						1*	1
	Centrifuge rotor							Launch after

								2004
	Life sciences glovebox					1*	1	1
	Service system					0.5*	0.5	0.5
	Stowage			0.5	0.5	0.2*	0.2	0.2
Cumulative total of racks on station		1.8	1.8	4.5	4.5	6.7	6.7	6.7

The figures show the number of Space Station racks, those with an asterisk indicate when the equipment items are to be launched for deployment in the Station.

8.15.2 Canada

The research programme in the space life sciences in Canada effectively started in 1984, with the emphasis initially on neuro-vestibular physiology. Canadian life sciences experimenters participated in a series of Spacelab missions (SL-1, D-1, D-2, SLS-1, SLS-2, IML-1), and a Canadian life sciences payload specialist, Dr R. Bondar, flew on the IML-1 mission.

Six Canadian experiments, in physiology, were performed on IML-1, covering the space adaptation syndrome (Dr D. Watt, McGill Univ.), positional and spontaneous nystagmus (Mr. J. McClure), energy expenditure in space flight (Dr H. Parsons, Univ. of Calgary), measurement of venous compliance (Dr B. Thirsk, CSA), back pain in astronauts (Dr P. Wing, UBC) and phase positioning experiment (Dr D. Brooks, UBC). Dr Watt, Dr Wing, and Dr Parsons, were similarly involved in experiments on STS-52 in October 1992. Canadian participation in other Shuttle and Spacelab flights are given within Tables 13 and 14.

Collaboration with the USSR began in 1987 and has continued, with collaborations on Russian satellite missions and an experiment set carried out on Mir. The 14 day Bion-10 mission included two Canadian experiments. One, by Dr R. Wassersug, was to investigate the development of the lungs and vestibular organs of amphibians in microgravity. Dr H. Ing carried out experiments on neutron radiation effects.

The Canadian programme in life sciences research currently supports work in the principal areas:

- *human physiology*, covering neurophysiology, cardiovascular physiology, metabolism and endocrinology, and musculoskeletal physiology;
- *space biology*, including gravitational biology, developmental biology, and physiology;
- *radiation*, which covers radiation (dosage) measurements, the effects on humans, and radiation biology.

Some 20 groups are currently supported for the various flight experiments, involving about 75 scientists, in total. Interest in continuing experimentation is high, with some 65 proposed experiments awaiting flight opportunities.

Future research activities will involve missions in the Spacelab, in the Mir space station, and the international space station. IML-2, scheduled for June 1994, will have a Canadian experiment on board entitled *Spinal Changes in Microgravity* (Dr J. Ledsome, of UBC), to study changes in the nervous system response and the spinal changes during spaceflight. A *Torso Rotation Experiment*, intended to study vestibular-eye-neck coordination, (Dr D. Watt, of McGill) is intended to fly on the Shuttle as a Mid-deck Secondary Payload, during 1994.

An *Aquatic Research Facility* is being constructed in Montreal, as a joint CSA/NASA project. It will allow the study of samples within a 100 ml. water volume, under microgravity, and within a 1 × g control volume. The first flight of the ARF is scheduled for 1995, with annual flights thereafter. The Principal Investigators for the first flight are: Dr B. Crawford (UBC), studying *The Effect of Microgravity on Early Starfish Morphogenesis* and Dr R. O’Dor (Dalhousie) *The Role of Gravity in Feeding and Development of Bivalve Larvae.*

Table 19. NASA Spacelab missions, with life sciences and materials sciences payloads

Missions	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	
SL-1 (9 days)	▲	Neurovestibular, Blood Studies, Space Biology, Materials and Fluid Sciences														1
SL-3 (7 days)2			▲	Metabolic, Neurovestibular, Hardware Verification, Materials and Fluid Sciences												
SL-2 (8 days)			▲	Musculoskeletal, Plant Biology												
SL-D1 (7 days)			▲	Cardiovascular, Neurovestibular,Space Biology, Plant Biology, Material and Fluid Sciences												
SLS-1* (9 days)									▲	Cardiovascular/Cardiopulmonary,Metabolic, Musculoskeletal, Neurovestibular, Medical Technology,Combustion						
IML-1 (7 days)										▲	Neurovestibular, Human Performance, Radiation, Cell Biology, Plant Biology, Materials and Fluid Sciences, Critical Point Studies, Protein Crystal Growth					
USML-1** (13 days)										▲	Materials and Fluid Sciences, Protein Crystal Growth, Combustion					
SL-J (7 days)										▲	Cardiovascular Countermeasures, Gravitational Biology, Materials and Fluid Sciences, Protein, Crystal Growth					
SL-D2 (10 days)										▲	Cardiovascular/Fluids, Cell Fusion, Materials and Fluid Sciences					
SLS-2* (13 days)											▲	Cardiovascular, Metabolic, Musculoskeletal, Neurovestibular				
IML-2 (13 days)												▲	Performance, Space Biology, Protein Crystal Growth, Electrophoresis, Vibration Isolation Studies, Materials and Fluid Sciences			
USML-2** (16 days)													▲	Materials and Fluid Sciences Protein Crystal Growth		
MSL-1															▲	Experiment Selection
SLS-4*															▲	(Anthrorack, Biorack)? (Rhesus Facility) Neurophysiology

*Life Sciences Dedicated Missions** Material Sciences Dedicated Missions

Neurolab, intended for a 1997 launch, will probably have one or more Canadian experiments included. 12 Proposals were submitted for review. Russian missions and cooperations will continue. Radiation studies on Mir are planned to continue (Dr H. Ing and Dr I. Thompson), and studies on metabolism (Dr H. Parsons) with Russian experimenters are intended for Mir missions. Dr B. Glickman (Univ. of Victoria) will continue studies on the mutations that occur in cosmonauts after spaceflight.

8.15.3 Russia

The political and financial problems of the Russian Commonwealth of Independent States in recent times appears to have caused a slow-down in the space life sciences research programmes. Despite this, space experiments in this field continue to be undertaken, many now involving collaborative ventures with other European countries, and also with America.

In addition to the RKA, the Russian Space Agency, there are several space enterprises which are acting as commercial companies and arrange for spaceflights involving the Mir space station and also specialized satellites.

An agreement between the RKA and ESA was made in October 1992, which included microgravity research activities and which committed ESA to two missions to Mir by European astronauts. These were planned to occupy 1 month in 1994, and 4 to 5 months in 1995, and will permit the use of Mir facilities. Arrangements for flights of this type have also been made by several ESA Member States (e.g. France, Germany and Austria), and have included substantial programmes of life sciences research. A summary of these flights, and associated life sciences programmes, is given in Table 15.

Table 15. Recent Russian Mir based life sciences experiments involving ESA member states

Topic(s)	Principal Investigators	Affiliation
French/Russian *Aragatz* mission, 26 November to 21 December, 1988		
Study of the radiation environment of the Mir space station (CIRCE experiment).	V.M. Petrov *et al.*, V.D. Nguyen, J. Kerlach, M. Siegrist, J.F. Zwilung, A. Akatov *et al.*	Comm. Energ. Atomiqu;, CNES & IBMP, Moscow
Explore constraints on visual image processing and operational performances (VIMINAL experiment); mental rotation of 3D shapes in microgravity.	Y. Matsakis, A. Berthoz, M. Lipschitz, V. Garfinkel	Lab. Physio. Neurosens. & Inst. Prob. Transp. Inform.
Study of postural and locomotor systems and the state of sensorial organs (PHYSALIE experiment).	V.S. Gurfinkel, *et al.* F. Lestienne, L. Lefort, C. Andre-Deshays *et al.*, J.P. Roll *et al.*, K. Popov, M. Lipschitz	Lab. Physio. Neurosens. & Inst. Prob. Transp. Inform., Univ. de Provence
Study of the cardio-vascular system (ECHOGRAPHIE 4 experiment).	P. Arbeille *et al.*, J.L. Cretien, O. Atkov, V. Bystrov *et al.*, G. Fonina *et al.*	INSERM 316, Tours; CNES, Paris, Centre of Cardiology & IBMP, Moscow
Study of water and mineral metabolism and hormonal regulation (MINILAB). Volume regulating hormones, fluid and electrolyte modifications.	G. Gauquelin *et al.*, M.Patrilot, J.L. Cretien, A. Guell, R. KvetnanskY, L. Macho, A. Grigoriev *et al.*	Lab. Environ. Physio, Lyon, Centre Hosp. Lyon Sud; CNES, Toulouse; Inst. Exp. Endocrin, Bratislava & IBMP, Moscow
Influence of space flight on human T-lymphocyte and monocyte functions.	L. Schaffar *et al.* I. Konstantinova *et al.*	INSERM Uzio, Nice & IBMP, Moscow

Study of bone tissue mineralization. Bone densitometric results with the SCOOP miniscanner.	C. Alexandre *et al.* P. Ruegsegger	LBTO, France, Inst. Techn Biomed.
Austrian/Russian *Austromir* mission, 2 to 10 October, 1991		
Investigation of genetic changes in lymphocytes, their possible repair and immunological effects (MIRGEN).	H. Tuschl *et al.*, M.S. Chajdakow, Y.J. Voronkov	Öst. Forsch Zent. Siebersdorf & IBMP, Moscow
Disturbances in movement coordination following stimulation with visual, acoustic and proprioceptive stimuli. Eye-head-arm coordination and spinal reflexes in weightlessness (MONOMIR)	M. Burger, F. Gersten Brand *et al.*, E. Hochmair, G. Steinwender, A. Sokolov *et al.*, I.B. Kozlovskaya	Neurology Dept. and Physics Dept. Univ. Innsbruck & IBMP, Moscow
Force-angle velocity relationship of musculature in/against predetermined translatory movement & correlation with integrated surface EMG.	N. Bachl, R. Baron, K.H. Tschan, M.Mossaheb, W. Bumba, F. Hildebrand, I. Kharitonov	Sports & Exercise Dept., Univ. of Vienna & IBMP, Moscow
Measurement of attention, psychomotor speed, mental feasibility, time estimation, visuospatial perception, memory, function changes. A study of cognitive functions in microgravity (COGIMIR).	T. Benk, F. Gerstenbrand, B. Koserenko, N. Watson	Neurology Dept. Innsbruck Univ.; IBMP, Moscow & Univ. Brit. Columbia
Accuracy of directional hearing and its role in human orientation in microgravity.	A. Persterer, C. Koppensteiner et al., M. Berger, M. Nefjodova	AKG, Vienna, Univ. of Innsbruck & IBMP, Moscow
Examine the vertical vection illusion elicited by an optokinetic stimulator system. Orientational effects from optokinetic stimulation (OPTOVERT).	C. Muller, G. Wiest, L. Deecke, L. Kornilova	Neurology clinic, Univ. Vienna, IBMP, Moscow
Monitoring of cardiovascular parameters during space flight.	M. Moser, E. Gallasch, *et al*, R. Bayevskij, I. Funtowa *et al*	Physiolog. Inst., Univ. of Graz & IBMP, Moscow
Influence of tremor parameters of the changes to muscle loading/proprioreceptor threshold levels	E. Gallasch, M. Moser *et al.*, I. B. Kozlovskaya, M. Borlov	Physiolog. Inst., Univ. of Graz & IBMP, Moscow
Changes to dynamics of transcapillary fluid shifts in microgravity.	H.G. Hinghofer-Szalkay *et al.*, J. Schmeid, H. Heimel, V.B. Noskov, I. Pestov, A.I. Grogorien	VRSM, Univ. of Graz; Lab. Messtechnik, Graz & IBMP, Moscow
Radiation measurements inside the soviet space station mir (DOSIMIR). Thermoluminescent dosimeters and track etch foils to measure average LET and absorbed dose.	N. Vana, W.Schoewer, M. Fugger, J. Akatov	Atominst., Univ. of Vienna & IBMP, Moscow
German/Russian *Mir 92* mission, 17 to 27 March, 1992		
Monitoring of kidney response from beginning of mission, in comprehensive manner, including stress, drug intake, circadian rhythms.	R. Gerzer, C. Drummer, M. Hear, R.A. Dressendörfer, C.J. Strasburger	Klinik Innestadt, Münich & DLR, Flugmedizin, Cologne
Fluid shifts into/out of superficial tissues under microgravity and terrestrial conditions.	K.A. Kirsch, F.J. Baartz, H.C. Gunga, L. Rocker	Inst. for Physiology, Free Univ., Berlin
Determination extent to which fluid deficit is due to interstitial fluid losses and LBNP effect.	F.J. Baisch	DLR, Inst. Flugmedizin, Cologne
Changes in interocular pressure due to fluid shifts.	J. Draeger, R. Schwartz,	Univ. Hospital, Eppendorf
Influence of microgravity induced fluid loss on heart rate/blood pressure after leg exercise compared to 1 <mult> g dehydration effects.	D. Essfeld, K. Baum, U. Hoffmann, J. Stegemann	Physiol. Institute Deutsche, Sporthochschule, Cologne
Dosimetry in space. Plastic track detectors, emulsions,	G.Reitz, R. Beaujean, N.	DLR, Inst. Luft- und

thermoluminescence detectors combined with chromosomal analysis. Sleep and circadian rhythm during a short space mission.	Heckley, G. Obe A. Gundel, E.Reucher, M. Vejvodva, J. Zulley, V. Nalishiti	Raumfahrtmedizin Cologne, Univ. Kiel; Univ. G.H., Essen DLR, Inst. Luft- und Raumfahrtmedizin MPI Psychiatrie, Münich & ZPK, Star City
Tests of logical reasoning, decision making, memory retrieval, fine manual control, compared in flight with pre/postflight Illusions of verticality in weightlessness Separation of canalicular and otolithic contributions to ocular torsion. Vestibulo-oculomotor testing during space flight Clarification of interaction between visual, proprioceptive, and vestibular inputs to the equilibrium system. Test of otolith asymmetry, and relationship to motion sickness	D. Manzey, B. Lorenz, A. Schiewe, G. Finell, G. Thiele H. Mittelstaedt, S. Glasauer A.H. Clarke, W. Teiwes, H. Scherer K. Hoffstetter-Degen J.Wetzig, R. Von Baumgarten K. Hoffstetter-Degen J.Wetzig, R. Von Baumgarten	DLR, Inst. Luft- und Raumfahrtmedizin Cologne & DLR, Astronautenburo MPI Verhaltenphysiologie, See-wiesen; Neurolog. Klinik, Grosshadern, Münich HNO Klinik, Klinikum Stieglitz; Free Univ., Berlin Physiolog. Institut J.G. Univ., Mainz Physiolog. Institut J.G. Univ., Mainz
French/Russian *Antares* mission, July to August, 1992		
Determination of ANP and aldosterone modifications, assess role of cortisol as stress indicator, urine output monitoring, HRV and baroflex sensitivity before and after flight and interrelationships.	A. Maillet, C. Gharib, *et al.*, D. Vorobiev *et al.*, A. Soloviev *et al.*, R. Cartier, M. Patricot, M. Tognini	Lab. Phys. Environ., Univ. Lyon; IBMP, CPK, Moscow; Hosp. Cardiologique, Lyon & CNES, Toulouse
To characterize the functional activity of subset of natural killer cells during a long space mission. Mechanisms of anti-viral resistance (IMMUNOLOGIE). To determine whether mental transformation processes, proposed for visual image processing, are influenced by microgravity conditions.	I.V. Konstatinum, *et al.*, D. Schmitt, C. Peres A. Berthoz, G. Leone, M. Lipshits, V. Gurfinkel, Y. Matsakis	IBMP, Moscow & CNES, Toulouse Lab. Phys. Neurosens. CNRS; Inst. Info-trans. Prob, Moscow & NEDES, Toulouse
Study of adaptive processes in human proprioceptive functions at cognitive and sensorimotor levels in weightlessness.	J.P. Roll, R. Roll, C. Quoniam, J.C. Gilhodes, O. Charade	Lab. Human Neurobiol., Klinik Provence, Marseille lab. Neurosens, CNRS
Assessment of main cardiac and vascular haemodynamic changes, using an ultrasound space device.	N. Arbielle, J.H. Pottier, A. Roncin, G. Fomina, A. Kotovskaya	Fac. Medicine, Univ. Toulouse & IBMP, Moscow
Study of DNA base lesions upon exposure of cellular DNA to high LET components (BIODOSE)	J. Cadet *et al*, L. Sabatier, L. Nevzgodina	SESAM/DRFMC, DPTE/LCG & IBMP, Moscow
Real dose rate and LET spectrum on Mir using a cylindrical gaseous low pressure and tissue equivalent proportional counter.	V.D. Nguyen *et al.* C. Andre-deshays, *et al* S.B. Koslova, V.M. Petrov	CEA ISPN/DPMD/SDOS, Fontenay; CNES, Toulouse & IBMP, Moscow
French/Russian Altair mission, July to August, 1993 (mostly extensions of studies carried out on the *Antares* mission of 1992)		
Study of human spatial orientation (ILLUSIONS)	J.P. Roll, J.C. Gilhode *et al.*	LNH, Marseille
Study of role of visual motor memory in operational activities (VIMINAL)	A. Berthoz *et al.*	LPN, Paris
Study of cosmic radiation dose distribution laws (NAUSICAA)	M. van Dat	CEA/IPSM
Study of changes in the immune defence system (IMMUNOLOGIE)	D. Schmitt *et al.*	INSERM

Biological dosimeters and the effect of space radiation (BIODOSE)	J. Cadet, L. Sabatier *et al*.	CEA
Study of cardiovascular deconditioning and of hormonal systems involved in blood volume regulation (ORTHOSTATISME)	P. Arbeille, J.M. Pottier, C. Gharib	LBM, Tours; LPE, Lyon
Study of limb/body movements in microgravity (SYNERGIES)	J. Masson, M. Pozzo	LNM, Marseille; LERPS, Dijon

In addition to these programmes involving the Mir space station, which emphasise human physiology, ESA and individual European countries have participated in the Bion series of recoverable satellites, in order to carry out space biological research. The Bion Programme is based upon the Foton spacecraft system, the first of which was launched in 1985, and was used on that occasion for experiments in materials science. The spacecraft has three distinct units: the power supply module, the instrument module,and the descent vehicle containing the payload. The latter is separated just prior to re-entry, and is equipped for an eventual soft landing.

For the Bion programme, the descent capsule has a pressurized unit, and is designed to allow for late access. In addition to this pressurized unit, special containers are attached to the outside of the descent vehicle to provide the opportunity for experimentation under outer space conditions, to support radiation and exobiology studies.

Basic characteristics of the Bion system are: an orbit of 220 to 300 km with an inclination of 62.8^o; payload mass of 700 kg with a volume of 4.7 m^3; temperature range 15 to 28^o C; pressure, 730 to 770 mm Hg; pO_2, 140 to 180 mm Hg; pCO_2, less than 2 mm Hg; humidity 60%. The vehicle provides experiments with an average power supply of 400 W, the maximum being 700 W for 1.5 h d^{-1}. Microgravity duration is 14 to 16 days, the quality being better than $10^{-4} \times g$. Late access is available up to 8 to 10 h before launch, and with early retrieval the experimental material is accessible 12 h after landing.

The NIKA-T is a new re-entry satellite , with 1995 as the original planned commissioning date. The mission duration is intended to be 3 to 4 months. It will provide a capsule specifically designed for medical and space biology experiments, with considerable improvements on the Bion design. Payload mass is expected to be some 1,200 kg, and the power supply capability is of the order of 4 to 5 kW.

The Bion Scientific Programme has been operated by the Institute for Bio-Medical Problems (IBMP), Moscow. The Bion 8 mission, of September 1987, contained three autonomous experiments supported by ESA, all of which were concerned with the effects of cosmic radiation and microgravity. The Bion 9 mission, of September, 9 1989, contained 5 ESA supported experiments, and the Bion 10 mission of Dec. 1992, had eight experiments and involved some 50 investigators. As in the previous missions, the Bion 10 experiments involved a considerable amount of collaboration with Russian experimenters, many from the IBMP. Details of these experiments are provided in Table 16. This series of Bion missions also contained monkeys as subjects for research into the physiological changes and adaptations to weightlessness during the early phases of space flight.

The Mir Space Station complex consists of the basic module, which has two axial and four side docking units, a scientific module, and the manned and unmanned transport spacecraft. The actual configuration is modified as required to support the emphasis of on-going programmes by the introduction of programme dedicated flight modules. A large module was originally intended for biological and medical research programmes. Called the Medilab, this had been under design for several years, and was originally intended for a 1995 launch. It now looks highly unlikely.

Table 16. Recent Russian (CIS)/ESA-member states collaborations on the Bion spacecraft

Mission	Date	Topic	Authors	Affiliation
Bion 8 (Cosmos 1887)	29-9-87	Study of combined effects of microgravity and cosmic radiation on early stages of -development in eggs of the stick insect, *Carausius morosus.*	G. Reitz *et al.*	DLR, Germany & IBMP, Moscow
Bion 8 (Cosmos 1887)	29-9-87	Radiation dosimetry in/outside the BIOKOSMOS (Bion) satellite.	G. Reitz *et al.*	DLR, Germany & IBMP, Moscow
Bion 8 (Cosmos 1887)	29-9-87	Biological damage induced by ionizing cosmic rays in dry *Arabidopsis* seeds.	A.R. Kranz *et al.*	Univ. Frankfurt, IBMP, Moscow & Inst. Developmental Biol., Moscow
Bion 9 (Cosmos 2044)	15-9-89	Study of combined effects of microgravity and cosmic radiation on early stages of development in eggs of *Carausius morosus.*	I.A. Ushakov, A.M. Alpatov & G. Reitz	IBMP, Moscow, DLR, Germany
Bion 9 (Cosmos 2044)	15-9-89	Radiation dosimetry in/outside Bion 9.	G. Reitz *et al.*	DLR, Germany & IBMP, Moscow
Bion 9 (Cosmos 2044)	15-9-89	Biological effects of ionizing cosmic heavy particles on embryonic plant tissues in seeds.	A.R. Kranz *et al.*, K.E. Gartenbach *et al.*	Univ. Frankfurt, IBMP & Inst. Developmental Biol., Moscow
Bion 9 (Cosmos 2044)	15-9-89	Effects of microgravity on regeneration of plants from protoplasts	T.H. Iversen *et al*, O. Rasmussen	Inst. Mol. Biol. Aarhus, Denmark; ETH, Zürich & IBMP, Moscow
Bion 9 (Cosmos 2044)	15-9-89	Microgravity and space radiation effects on *Drosophila melanogaster*: development, ageing, mitotic recombination rate and adaptation.	R. Marco et al.	Univ. Alicante & Univ. Madrid, Spain & IBMP, Moscow
Bion 10 (Cosmos 2229)	29-12-92	Test of the metabolic hypothesis of accelerated ageing in *Drosophila* in space	J. Miguel, R. Marco	Univ. Alicante & Univ. Madrid, Spain & IBMP, Moscow
Bion 10 (Cosmos 2229)	29-12-92	Impact of pre-flight gravity stress on in-flight fitness in *Drosophila melanogaster*	R. Marco, J. Gonzalez-Jurado, M. Maroto, J. Miguel, I.A. Ushakov, A.M. Alpatov	Univ. Alicante & Univ. Madrid, Spain & IBMP, Moscow
Bion 10 (Cosmos 2229)	29-12-92	Ultrastructural changes in dividing *Chlamy-domonas monoica* cells due to microgravity.	H. van den Ende, E. van Spronsen, O.V. Gavrilova	Univ. Amsterdam & Univ. St. Peters-burg
Bion 10 (Cosmos 2229)	29-12-92	Analysis of chromosomal damage of marker lines of *Arabidopsis* seeds by heavy cosmic particles.	A.R. Kranz, J.U. Schott *et al.*, V.V. Shevchenko, A.M. Marenny *et al.*	Univ. Frankfurt, RCSRS, IBMP Moscow
Bion 10	29-12-92	Identification and quantification of incident	G. Reitz, R. Facius *et*	DLR, Germany;

(Cosmos 2229)		radiation particles during flight and biological effects on *Wolffia arrhiza*.	*al.*, L.V. Nevsgodinna, E.N. Maximova, A.M. Marenny *et al.*	IBMP, Moscow & RCSRS, Moscow

Within the basic module of Mir are provisions for the working and the relaxation of crew, together with the control of Station elements, power, and data transmission systems. The RKA also has within Mir various facilities for microgravity research which are made available to users on a commercial basis, for example, the units Biokryst and Ainur, used for crystallization of proteins, the Ruchei electrophoresis apparatus, the Rekomb reactor for cell hybridization, and the microcultivator Vita.

Well over 80 studies in space biology have been performed in the Mir station over the past 3 years. The Svetoblock-M, Magnetogravistat, Vazon, and other equipment have been used for studies on the growth and development of higher plants, involving some 20 species. The Bioterm-10 and Rost-4M apparatus were used to study changes in the development of plant tissue cultures, exposed to open space conditions. The equipment designated Inkubator 2, Ovanzhereya, and Svet, were used for the study of modifications to the embryonic and post-embryonic development of birds. Human physiology and medical experiment have also been a major feature of the Mir research programmes. Planning for the progressive extension of Mir capabilities and the development of an International Space Station is proceeding now (see Section 8.15.1.2).

The Russian life sciences programme for the future International Space Station has only been defined in rough outline. It is clear however, that it is heavily biased towards the practical aspects of manned space flight, together with more basic research programmes which are intended to contribute towards Earth based research, often of an applied nature. In *space medicine*, the emphasis is upon establishing and maintaining optimal crew health, following the adaptation process, determining the most effective residence period in space, and exploring the results of extended space exposure, comparable with the expected duration of a manned Mars mission. Equipment will include an ultrasound cardiograph, 'biopotentials' indicator, centrifuge, cryogenic (O_2) refrigerator, cardiac recorder, heat and mass measuring devices.

The *biology* research programme will extend from that performed with the Salyut and Mir Space Stations. No details have been given, merely a statement that it will cover the subcellular through to organism range. There is, however, a strong emphasis on research connected to life support systems, biotechnology, and applied biology. The equipment foreseen is primarily a greenhouse, with a growth/lighting section, and control unit, and a centrifuge, together with microscope, gas analyzer, and sample preparation equipment. *Biotechnology* covers the biological dynamics of cells in cultivation, the mechanisms of cell fusion, separation and purification of genetically engineered virus proteins and their extraction by electrophoresis and other methods. Experimental and pilot production of biological materials will be undertaken, including pharmaceutical, diagnostic, and prophylactic preparations, hybrid cells and micro-organisms, together with microcrystals, biopolymers, and viruses. The equipment will include the Ruchei-2M electrophoresis units, a Recomb-2 unit, the Luch-2M biocrystallization unit, the Biocryst-2M crystallization unit, Bioproduct analysis system. The total mass of equipment for biotechnology, accommodated in habitation modules, is about 2,500 kg, and the consumables throughput is estimated at 4,500 kg y^{-1}.

8.15.4 Japan

A substantial space programme is being progressively established by Japan, through its agency NASDA. Research in the life sciences is considered an important element, with some emphasis on the human physiology aspects being evident, due to the interest in manned space activities. The other areas of microgravity life science research are also being supported however, as indicated by the complement of Japanese experiments on the joint NASA-NASDA Spacelab-J (STS-47) mission, which took place in September 1992. These are listed below.

Human physiology. Health monitoring of the Japanese payload specialist, monitoring of heart rate, blood pressure, and respiration rate; and blood.(principal investigator Dr Sekiguchi, NASDA) and urine sampling to study endocrine and metabolic changes in the payload specialist.(principal investigator Dr N. Matsui, Nagoya University).

Neurophysiology. Comparative measurement of visual stability on Earth and in microgravity, eye, head and neck movements and their relationship to spatial coordination (principal investigator Dr K. Koga, Nagoya University); research and perceptual motor functions in microgravity, tracking and handling operations studied to explore potential future improvements by automation. (principal investigator Dr A. Tada, National Aerospace Laboratory); neurophysiological study of visuo-vestibular control of posture and movement in fish during adaptation to microgravity, response of fish with the gravity sensing organs removed are compared to the behaviour of normal fish, to contribute to the study of the conflict theory of space motion sickness (principal investigator Dr S. Mori, Nagoya University).

Cell biology. Effects of microgravity on the ultrastructure and functions of cultured mammalian cells, investigation of the changes in internal organisation and enzyme production of cultured cells in microgravity (principal investigator Dr A. Sato, Tokyo Medical and Dental Univ.); study of the effects of microgravity on cell growth of human antibody producing cells and their secretions, changes in growth rate, antibody producing capability, and morphology of immune hybridoma cells (principal investigator Dr H. Ooka, Tokyo Medical and Dental Hospital); organ differentiation from cultured plant cells under microgravity, effects on cell division, cell differentiation, and the growth of plant cells (principal investigator Dr Y. Yamada, Kyoto University); circadian rhythm of conidiation in *Neurospora crassa*, effect of microgravity on the rhythm of this mould in order to determine if this is endogenous or due to geophysical factors (principal investigator Dr Y. Miyoshi, Tokyo University).

Developmental biology. Effects of microgravity on calcium metabolism and bone formation, investigation of bone formation in chicken embryos (principal investigator Dr T. Suda, Showa University).

Radiation biology. Genetic effects of HZE and cosmic radiation, study of effects on *Drosophila melanogaster* (fruit flies) (principal investigator Dr M. Ikenaga, Kyoto University); study of the biological effect of cosmic radiation and the development of radiation protection technology. Radiation track detectors and biological specimen, to study the effects of HZE particles (principal investigator Dr S. Nagaoka, NASDA).

Biotechnology. Separation of biogenic materials by electrophoresis, free flow electrophoresis to separate and purify a sample of mixed proteins (principal investigator Dr M. Kuroda, Osaka University); separation of animal cells and cellular organelle by free flow electrophoresis, study of the effectiveness of electrophoresis to obtain a pure strain of bacteria (principal investigator Dr T. Yamaguchi, Tokyo Medical and Dental Inst.); crystal growth of enzymes, protein crystal growth for structural analysis (principal investigator Dr Y. Morita, Kyoto University).

Japanese life scientists were also involved with experiments on the Spacelab SLS-2 mission, in October 1993. Three post flight experiments were carried out, covering the study of bone metabolism in microgravity, histochemical and biochemical studies of heart muscle changes in rats, and the effects on β-adrenoreceptors in rat hind limb muscles.

Collaborative programmes with NASA have continued to be a feature of Japanese planning. The IML-2 Spacelab mission, scheduled for launch in mid-1994 will also contain Japanese experiments. These are principally materials science experiments, but include studies of calcium metabolism, motion sickness, radiation experiments on biological samples, chromosome separation experiments, and protein crystallization studies.

Planning for participation in the SLS-4 (Neurolab) mission, in 1998, is now under way. Some 21 life science experiments proposals have been submitted from Japan. Of these 3 are concerned with behaviour and cognition, 5 with cellular and neurobiology, 3 with developmental neurobiology, 4 with homeostasis of the nervous system, and 6 with the sensory and motor system.

Small experiment payloads, destined for the Mid-Deck locker location in the Shuttle, are also being planned. They cover the general fields of space biology, physiology, and countermeasures. Small short term experiments are also performed using a DAS MU-300 aircraft for parabolic flights.

The JEM pressurized module will be a major contribution by Japan to the International Space Station. Due to be in place by the year 2002, it will open up a major opportunity to expand the Japanese space life sciences programme.

In the meantime, Japan is evidently moving to establish a considerable degree of autonomy for its overall space programme in the future. This is based upon a range of Japanese launchers, the largest of which, H-II, will be ready for service in 1994. This vehicle will have a payload capability similar to that of the Ariane IV (9 ton into low earth orbit, 2 ton into geosynchronous orbit). The intention has been to develop an unmanned space plane, the HOPE, to be launched into orbit by an uprated H-II, in order to provide logistics support to a manned space station element, such as the JEM. It is not clear at present if that plan will continue.

The first flight of the so-called Space Flyer Unit is due to occur in 1995. This is a re-usable, free flying platform which is designed to operate autonomously in space over a period of months. The launch will take place using the H-II rocket; with recovery by the Shuttle. Like the ESA Eureca platform, the SFU can be used for longer term biology experimentation. The first flight will include automated experiments on chromosome separation and protein crystallization.

A specific programme of 3 missions dedicated to space biology is planned for the period 1996 through 1998. This programme will be based upon the Japanese J-1 three stage rocket, which has a payload capacity of some 800 kg, into low earth orbit. The intention is to develop a recoverable biology payload unit, the J-Lifesat, somewhat along the lines of the Russian Bion space modules.

8.15.4.1 LIFESAT missions

Each of the three LIFESAT missions will be focused on one scientific goal. Reference experiments have been outlined within that framework and these may be summarized as follows.

Mission 1, study of the biological effects of space radiation relevant to JEM crew. The experimental objectives are broadly to collect cosmic radiation environment data in low earth orbit, both inside and outside the vehicle, conducting long term exposure of a mammal (mouse) to obtain data on the chromosomal change and tumour formation. The orbit altitude will be 300 to 400 km, the mission will last up to 60 days and the experiment will feature real time radiation monitoring. Carcinogen will be administered before flight to raise the cancer rate and in flight tumor induction at the cellular level, chromosomal changes and damage and induction of somatic mutation will all be monitored. The experimental animals will be 20 male or female mice. Ground controls will feature identical animals given controlled exposure to gamma-rays and X-rays and there will be simulation of launch vibration for the tumour induction test group. Postflight analysis will include studies of the cellular functions, chromosomal mutations and aberrations, pathogenic anatomical and molecular biological analysis of tumours, haemocytometer analysis, and mineral bone density measurements.

Mission 2, study of bone, muscle and activity in microgravity. Experiment objectives in this case are study of calcium desorption or demineralization in mouse bone, post-flight mineral recovery, bone formation, muscle atrophy, and otolith deformation. Again 20 male or female mice will be used and some will be subjected to pre-flight drug administration to study pharmacological countermeasures for osteoporosis prevention. The mission period will be up to 60 days with full animal life support and physiological data (heart rate, temperature, electromyogram) acquisition by telemetry. Ground controls will include immobilization of hind-limb muscles. Postflight analysis of the bones will include bone stroma proteins, calcium balance, dynamic tests, morphology, biochemical, bone mineral density, amino acid and mineral contents. Muscle analysis will cover the stretching and soleus muscle characterization together with muscle protein characterization. The studies will also include blood mineral analysis, and urea/faeces analysis, and a detailed study of the morphology and biochemistry of the vestibular apparatus.

Mission 3, pathological physiology in microgravity. Experiment objectives will be to obtain data on the immunological and haematopoietic functions, drug metabolism, infection and care for health maintenance in space. The flight details will be the same as the previous two missions; duration will be similar. 20 male/female mice will be used, with heart rate and temperature monitoring. Photographic records will be made of colour (still) images at the rate of 1 frame h^{-1}. Postflight analysis will examine immunological functions in depth, including the pathological test of immunological organs, functional tests of lymphocytes and the study of bacterial infection, including the intestinal bacteria. Haemostatic studies, coagulation and fibrinolytic factor determinations, and the analysis of haematopoietic functions will be carried out.

Apart from the Lifesat programme, the major effort in the Japanese long term plan for experimentation in the life sciences lies in collaborations on future Spacelab flights with NASA (especially IML-2), leading to the introduction of the JEM onto the Space Station.

8.16 ESA space life sciences programme

Initially, the ESA Life Sciences experiments were largely exploratory in nature, as is to be expected with a new research activity. Progressively the move has been towards the establishment of reliable data sets on the different phenomena that have been observed. More recently this emphasis has been changing again, as interest focuses on in-depth studies of the different phenomena. It is the recognition of that change which has prompted ESA to initiate this examination of the world-wide trends in the microgravity life sciences research.

Table 20. Development of ESA's unmanned life sciences experiments

Mission	Date	Facility	Research topics
Biocosmos 8 (USSR-ESA)	1987 (5 days)	Biorack type 1 container	Radiation biology Dosimetry
Biocosmos 9 (USSR-ESA)	1989 (10 days)	Biorack type 1 container	Cell developmental biology Radiation biology
Foton (Russia-ESA)	1992 (11 days)	Biopan	Test flight: minimum shielding
EURECA (ESA)	1992-1993 (9 months)	ERA	Radiation biology, Dosimetry Solar UV radiation Survival of primitive life forms
Biocosmos 10 (Russia-ESA)	1992-1993 (12 days)	Biobox	Cell molecular biology Calcium metabolism Radiation biology Dosimetry
Foton (ESA)	1993 (14 days)	Biopan	Exobiology Cell-biology Radiation biology
Foton (ESA)	1994 (14 days)	Biobox	Cell molecular biology Developmental biology Radiation effects on metabolism
Foton (ESA)	1996-1997 (28 days)	Biobox Biopan	To be decided To be decided

The intention is to try to define more clearly the future subjects for study, in order to concentrate more effectively the limited resources which ESA has at its disposal. The development of the ESA life sciences programme can be seen in Tables 20 and 21 which cover the unmanned, principally biology, research missions and then the manned missions, which include also the human physiology research activities.

Table 21. Development of ESA's life sciences programme on manned laboratories.

Mission (partners)	Date (duration)	Facility	Research topics
Spacelab SL-1 (NASA/ESA)	1983 (9 days)	Sled/BRS	Neuro-vestibular physiology Cardiovascular physiology Cell biology, Dosimetry
Spacelab D-1 (Germany/ESA)	1985 (10 days)	Biorack Sled	Cell/molecular/developmental biology, Radiation biology Neurovestibular physiology
Spacelab SLS-1 (NASA/ESA)	1991 (10 days)	Incubator	Cell biology/Immunology
Spacelab IML-1 (NASA-ESA-CNES-CSA-NASDA-DARA)	1992 (9 days)	Biorack	Cell, molecular & developmental biology
MIR-92 (Germany-ESA-Russia)	1992 (7 days)	Vesta	Oculo-vestibular interaction
Spacelab D-2 (DARA-ESA-NASA-NASDA-CSA-CNES)	1993 (9 days)	Anthrorack	Central/peripheral haemodynamics; cardio-pulmonary physiology; fluid volume regulation; metabolic processes (nitrogen turnover)
Spacelab IML-2 (NASA-ESA-	1994 (14 days)	Biorack	Cell-molecular biology

NASDA-CNES-DARA-CSA)			Radiation biology Developmental processes
EUROMIR 94 (ESA)	1994 (30 days)	Freezer, Centrifuge	Physiology, biology, radiation
EUROMIR 95	1995 (135 days)	Bone densitometer, VOG, RMS	Pulmonary, cardiovascular, musculo-skeletal, neurovestibular
Mir/SPEKTR (NASA/ESA)	1996 (continuous)	Torque Velocity Dy-namometer	Musculo-skeletal
Spacelab/Mir	1996 (4 missions)	Biorack	Biology, radiation
Spacelab SLS-4 (NASA-ESA-CNES-DARA-CSA-NASDA)	1998 (16 days)	BRS-Rotator Anthrorack-derived hardware (Neurorack)	Neurological/behavioural

Table 22. Experiments in biology and human life sciences (physiology and medicine) on the space shuttle (1981-1993) with European Principal Investigators

Mission	Flight	Launched	Title	Species used	Investigator	Affiliation	Country
SPAS-01	STS-7	18 Jun 83	Radiobiology mapping in Biostack.	Unspecified plant	M. Buchvald	German Youth Fair Programme (Jufo)	GER
SPAS-01	STS-7	18 Jun 83	Plant contamination by heavy metals (Cd transport).	Watercress	H. Katzenmeire	German Youth Fair Programme (Jufo)	GER
SL-1	STS-9	28 Nov 83	Radiobiology mapping: advanced biostack experiment.	Brine shrimp, *Artemia salina*	H. Buecker	DLR Cologne (DFVLR)	GER
SL-1	STS-9	28 Nov 83	Radiobiology mapping: advanced biostack experiment.	*Bacillus subtilis*	H. Buecker	DLR Cologne (DFVLR)	GER
SL-1	STS-9	28 Nov 83	Radiobiology mapping: advanced biostack experiment.	Tobacco, *Nicotiana tabacum*	H. Buecker	DLR Cologne (DFVLR)	GER
SL-1	STS-9	28 Nov 83	Radiobiology mapping: advanced biostack experiment.	Mouse-ear cress, *Arabidopsis thaliana*	H. Buecker	DLR Cologne (DFVLR)	GER
SL-1	STS-9	28 Nov 83	Radiobiology mapping: advanced biostack experiment.	Fungus spores (*Sordaria fimicola*)	H. Buecker	DLR Cologne (DFVLR)	GER
SL-1	STS-9	28 Nov 83	Microorganisms in hard space environment	*Bacillus subtilis*, spores	G. Horneck	DLR Cologne (DFVLR)	GER
SL-1	STS-9	28 Nov 83	Lymphocyte proliferation in weightlessness	Human	A. Cogoli	ETH Zürich	SUI
LDEF-1	STS-41C	06 Apr 84	Radiobiology in the free-flyer Biostack experiment	Brine shrimp	H. Buecker	DLR Cologne (DFVLR)	GER
LDEF-1	STS-41C	06 Apr 84	Radiobiology in the free-flyer Biostack experiment	*Bacillus subtilis*, spores	H. Buecker	DLR Cologne (DFVLR)	GER

LDEF-1	STS-41C	06 Apr 84	Radiobiology in the free-flyer Biostack experiment	Tobacco	H. Buecker	DLR Cologne (DFVLR)	GER
LDEF-1	STS-41C	06 Apr 84	Radiobiology in the free-flyer Biostack experiment	*Arabidopsis thaliana*	H. Buecker	DLR Cologne (DFVLR)	GER
LDEF-1	STS-41C	06 Apr 84	Radiobiology in the free-flyer Biostack experiment	Maize (*Zea mays*)	H. Buecker	DLR Cologne (DFVLR)	GER
LDEF-1	STS-41C	06 Apr 84	Radiobiology mapping: advanced biostack experiment.	Fungus spores (*Sordaria fimicola*)	H. Buecker	DLR Cologne (DFVLR)	GER
SL-D1	STS-61A	30 Oct 85	Microgravity and genetic recombination	*Escherichia coli*	O. Cifferi	University Pavia	ITA
SL-D1	STS-61A	30 Oct 85	Microgravity and genetic recombination.	Bacteriophage K1	O. Cifferi	University Pavia	ITA
SL-D1	STS-61A	30 Oct 85	Fruit fly embryogenesis and life span.	Fruit fly, *Drosophila melanogaster*	R. Marco	Universidad Autonoma Madrid	SPA
SL-D1	STS-61A	30 Oct 85	Endogenous rhythms in contraction and protoplasmic streaming.	Slime mould, *Physarum polycephalum*	V. Sobick	DLR Cologne (DFVLR)	GER
SL-D1	STS-61A	30 Oct 85	Radiobiology of embryogenesis and organogenesis	Stick insect, *Carausius morosus*	H. Buecker	DLR Cologne (DFVLR)	GER
SL-D1	STS-61A	30 Oct 85	Dosimetric mapping inside Biorack	Stick insect, *Carausius morosus*	H. Buecker	DLR Cologne (DFVLR)	GER
SL-D1	STS-61A	30 Oct 85	*Paramecium* growth and mineral properties	*Paramecium caudatum*	H. Planel	National Institute of Health, Toulouse	FRA
SL-D1	STS-61A	30 Oct 85	Bacterial growth and mineral properties	*Aerobacter aerogenes*	H. Planel	National Institute of Health, Toulouse	FRA
SL-D1	STS-61A	30 Oct 85	The biological clock of *C. reinhardii* in space.	*Chlamydomonas reinhardii*	D. Mergenhagen	University Hamburg	GER
SL-D1	STS-61A	30 Oct 85	Bacterial growth and differentiation.	*Bacillus subtilis*	H.D. Mennigmann	University Frankfurt	GER
SL-D1	STS-61A	30 Oct 85	Human lymphocyte activation in weightlessness.	Human	A. Cogoli	ETH Zürich	SUI
SL-D1	STS-61A	30 Oct 85	Effect of microgravity on lymphocyte action	Human	A. Cogoli	ETH Zürich	SUI
SL-D1	STS-61A	30 Oct 85	Graviperception of lentil seedling roots	*Lens culinaris*	G. Perbal	University Curie Paris	FRA
SL-D1	STS-61A	30 Oct 85	Ultrastructure of mammalian cell polarisation	Mouse lymphocytes	M. Boutelle	University Paris	FRA
SL-D1	STS-61A	30 Oct 85	Fertilisation and embryogenesis; dorso/ventral axis	Clawed toad, *Xenopus laevis*	G.A. Ubbels	Hubrecht Laboratory, Utrecht	NED

			establishment in embryos.				
SL-D1	STS-61A	30 Oct 85	Effectiveness of antibiotics in microgravity.	*Escherichia coli*	R. Tixador	National Institute of Health, Toulouse	FRA
SL-D1	STS-61A	30 Oct 85	Graviperception.	Garden cress, *Lepidium sativum*	D. Volkmann	University Bonn	GER
SL-D1	STS-61A	30 Oct 85	Graviperception and geotropism.	Maize, *Zea mays*	J. Gross	University Tübingen	GER
SL-D1	STS-61A	30 Oct 85	Graviperception and differentiation of plant cells	Anise, *Pimpinella anisum*	R.R. Thelmer	University Münich	GER
SL-D1	STS-61A	30 Oct 85	Graviperception (orientation); amphibian statolith experiment	Clawed toad, *Xenopus laevis*	J. Neubert	DLR Cologne (DFVLR)	GER
SLS-1	STS-40	05 Jun 91	Lymphocyte proliferation in weightlessness	Human	A. Cogoli	ETH Zürich	SUI
IML-1	STS-42	22 Jan 92	Bone and skeleton changes; mineralization and resorption of fetal bones	Mouse bone cells	J.P. Veldhuijzen	Free University Amsterdam	NED
IML-1	STS-42	22 Jan 92	Fertilisation and Embryogenesis Dorsal/ventral axis determination in embryos	Clawed toad, *Xenopus laevis*	G.A. Ubbels	Hubrecht Laboratory, Utrecht	NED
IML-1	STS-42	22 Jan 92	Development of *Drosophila* in space	Fruit fly, *Drosophila melanogaster*	R. Marco	Universidad Autonoma Madrid	SPA
IML-1	STS-42	22 Jan 92	Plant differentiation and regeneration from protoplasts	Carrot, *Daucus carota*	O. Rasmussen	University of Aarhus	DAN
IML-1	STS-42	22 Jan 92	Plant differentiation and regeneration from protoplasts	Rape, *Brassica napus*	O. Rasmussen	University of Aarhus	DAN
IML-1	STS-42	22 Jan 92	Radiobiology of embryogenesis and organogenesis of *C. morosus*	Stick insect, *Carausius morosus*	H. Buecker	DLR Cologne	GER
IML-1	STS-42	22 Jan 92	Dosimetric mapping inside Biorack	none	G. Reitz	DLR Cologne	GER
IML-1	STS-42	22 Jan 92	Growth and sporulation of *Bacillus subtilis*	*Bacillus subtilis*	H.D. Mennigmann	University Frankfurt	GER
IML-1	STS-42	22 Jan 92	Dosimetric mapping with the Biostack	*Bacillus subtilis*	H. Buecker	DLR Cologne	GER
IML-1	STS-42	22 Jan 92	Dosimetric mapping with the Biostack	Yeast spores, *Saccharomyces cerevisiae*	H. Buecker	DLR Cologne	GER
IML-1	STS-42	22 Jan 92	Dosimetric mapping with the Biostack	*Sordaria fimicola*, spores	H. Buecker	DLR Cologne	GER
IML-1	STS-42	22 Jan 92	Dosimetric mapping with the Biostack	Brine shrimp, *Artemia salina*	H. Buecker	DLR Cologne	GER

IML-1	STS-42	22 Jan 92	Dosimetric mapping with the Biostack	Mouse-ear cress, *Arabidopsis thaliana*	H. Buecker	DLR Cologne	GER
IML-1	STS-42	22 Jan 92	Friend Leukaemia virus transformed cells	Human erythrocytes	A. Cogoli	ETH Zürich	SUI
IML-1	STS-42	22 Jan 92	Hybridoma cell proliferation and performance	Human lymphocytes	A. Cogoli	ETH Zürich	SUI
IML-1	STS-42	22 Jan 92	Dynamic cell culture system	Syrian hamster kidney cells	A. Cogoli	ETH Zürich	SUI
IML-1	STS-42	22 Jan 92	Graviresponse of shoots and cotyledons in microgravity.	Mouse-ear cress, *Arabidopsis thaliana*	L.G. Briarty	University of Nottingham	UK
IML-1	STS-42	22 Jan 92	Transmission of the gravity stimulus in roots	Lentil, *Lens culinaris*	G. Perbal	Curie University Paris	FRA
IML-1	STS-42	22 Jan 92	Gravity related behaviour of *Physarum*	*Physarum polycephalum*	I. Block	DLR, Cologne	GER
IML-1	STS-42	22 Jan 92	Antibiotic penetration of bacterial cells in space	*Escherichia coli*	R. Tixador	National Institute of Health, Toulouse	FRA
EURECA	STS-46	01 Aug 92	Exposure experiment on the exobiology and radiation assembly (ERA)	*Aspergillus niger* spores	K. Dose	University of Mainz	GER
EURECA	STS-46	01 Aug 92	Exposure experiment on ERA	*Aspergillus ochraceus* spores	K. Dose	University of Mainz	GER
EURECA	STS-46	01 Aug 92	Exposure experiment on ERA	Yeast spores, *Saccharomyces cerevisiae*	J. Kiefer	University of Giessen	GER
EURECA	STS-46	01 Aug 92	Exposure experiment on ERA	*Bacillus subtilis* spores	G. Horneck	DLR, Cologne	GER
EURECA	STS-46	01 Aug 92	Exposure experiment on ERA	*Deinococcus radiodurans* spores	G. Horneck	DLR, Cologne	GER
EURECA	STS-46	01 Aug 92	Exposure experiment on ERA	*Ditlenchus dipsacii*	G. Horneck	DLR, Cologne	GER
SL-D2	STS-55	26 Apr 93	Dosimetric mapping	Dosimeters	G. Reitz	DLR, Cologne	GER
SL-D2	STS-55	26 Apr 93	Dosimetric mapping with the Biostack HZE tracking sandwich	Brine shrimp, *Arabidopsis*, fungal and bacterial spores	H. Buecker	DLR, Cologne	GER
SL-D2	STS-55	26 Apr 93	Vestibular reflexes in microgravity	Clawed toad, *Xenopus laevis*	E. Horn	University Ulm	GER
SL-D2	STS-55	26 Apr 93	Vestibular reflexes in microgravity	Cichlid fish, *Oreochromis mossambicus*	E. Horn	University Ulm	GER
SL-D2	STS-55	26 Apr 93	Development of the gravity perceiving organ	Clawed toad, *Xenopus laevis*	J. Neubert	DLR, Cologne	GER
SL-D2	STS-55	26 Apr 93	Development of the gravity perceiving organ.	Cichlid fish, *Oreochromis mossambicus*	J. Neubert	DLR, Cologne	GER

SL-D2	STS-55	26 Apr 93	CNS neuronal plasticity during ontogenesis.	Clawed toad, *Xenopus laevis*	H. Rahmann	University of Stuttgart	GER
SL-D2	STS-55	26 Apr 93	CNS neuronal plasticity during ontogenesis.	Cichlid fish, *Oreochromis mossambicus*	H. Rahmann	University of Stuttgart	GER
SL-D2	STS-55	26 Apr 93	Cerebellar development in microgravity	Clawed toad, *Xenopus laevis*	M. Schachner	University Heidelberg	GER
SL-D2	STS-55	26 Apr 93	Cerebellar development in microgravity	Cichlid fish, *Oreochromis mossambicus*	M. Schachner	University Heidelberg	GER
SL-D2	STS-55	26 Apr 93	Gravisensitivity of cress roots	Garden cress, *Lepidium sativum*	D. Volkmann	University Karlsruhe	GER
SL-D2	STS-55	26 Apr 93	Cell polarity and gravity	Garden cress, *Lepidium sativum*	M.H. Welsenseel	University Karlsruhe	GER
SL-D2	STS-55	26 Apr 93	Fruiting body development of fungi	*Flammulina velutipes*	B. Hock	Technical University Münich	GER
SL-D2	STS-55	26 Apr 93	Secondary metabolites in plant cell suspensions	*Panax ginseng*	H. Jung-Hellger	Plant Laboratory	GER
SL-D2	STS-55	26 Apr 93	Investigations on yeast metabolism	*Saccharomyces uvarum*	S. Donhauser	Technical University Münich	GER
SL-D2	STS-55	26 Apr 93	Productivity of bacteria	*Escherichia coli*	H.D. Mennigmann	University Frankfurt	GER
SL-D2	STS-55	26 Apr 93	Productivity of bacteria	*Bacillus subtilis*	H.D. Mennigmann	University Frankfurt	GER
SL-D2	STS-55	26 Apr 93	Effect on genetic material; fluctuation test on bacterial cultures	*Escherichia coli*	H.D. Mennigmann	University Frankfurt	GER
SL-D2	STS-55	26 Apr 93	Effect on genetic material; fluctuation test on bacterial cultures	*Bacillus subtilis*	H.D. Mennigmann	University Frankfurt	GER
SL-D2	STS-55	26 Apr 93	Bone and skeleton changes; collagen synthesis and cell proliferation	Human, skin fibroblasts	P.K. Mueller	University Lübeck	GER
SL-D2	STS-55	26 Apr 93	Activation of regulatory T-lymphocytes	Human T-lymphocytes	K. Reske	University Mainz	GER
SL-D2	STS-55	26 Apr 93	Growth of lymphocytes under microgravity	Human T-lymphocytes	K. Reske	University Mainz	GER
SL-D2	STS-55	26 Apr 93	Cell fusion and hybridoma production	Human B-Lymphocytes	U. Zimmermann	University Wurzberg	GER
SL-D2	STS-55	26 Apr 93	Electrofusion of plant cell protoplasts	Tobacco, *Nicotiana tabacum*	R. Hampp	University Tübingen	GER
SL-D2	STS-55	26 Apr 93	Electrofusion of plant cell protoplasts	Foxglove, *Digitalis* sp.	R. Hampp	University Tübingen	GER
SL-D2	STS-55	26 Apr 93	Electrofusion of plant cell protoplasts	Sunflower, *Helianthus* sp.	R. Hampp	University Tübingen	GER
SL-D2	STS-55	26 Apr 93	Radiobiology (mapping);	Mouse-ear cress,	H. Buecker	DLR Cologne	GER

			HZE-particle dosimetry with Biostack	*Arabidopsis thaliana*			
SL-D2	STS-55	26 Apr 93	Radiobiology (mapping); HZE-particle dosimetry with Biostack	*Artemia salina*	H. Buecker	DLR Cologne	GER
SL-D2	STS-55	26 Apr 93	Radiobiology (mapping); HZE-particle dosimetry with Biostack	*Sordaria fimicola*, spores	H. Buecker	DLR Cologne	GER
SL-D2	STS-55	26 Apr 93	Radiobiology (mapping); HZE-particle dosimetry with Biostack	Yeast spores, *Saccharomyces cerevisiae*	H. Buecker	DLR Cologne	GER
SL-D2	STS-55	26 Apr 93	Exposure experiment: responses to solar UV and space vacuum	*Bacillus subtilis*, spores	H. Buecker	DLR Cologne	GER
SL-D2	STS-55	26 Apr 93	Exposure experiment: responses to solar UV and space vacuum	*Bacillus subtilis*, spores	G. Horneck	DLR Cologne	GER
SL-D2	STS-55	26 Apr 93	Exposure experiment: responses to solar UV and space vacuum	Isolated DNA of the bacterium *Haemophilus influenzae.*	G. Horneck	DLR Cologne	GER
Human physiology and medical experiments							
SL-1	STS-9	28-11-83	Personal miniature electrophysiological tape recorder; data on heart, brain, eyes	Human	H. Green	Clinical Research Centre, Harrow	UK
SL-1	STS-9	28-11-83	Measurements of central venous pressure and hormones in blood; data on body fluid shifts	Human	K.A. Kirsch	Free University of Berlin	GER
SL-1	STS-9	28-11-83	Mass discrimination during weightlessness	Human	H.E. Ross	University of Stirling	UK
SL-1	STS-9	28-11-83	Comparison in cardiovascular performances; 3D ballistocardiography in weightlessness.	Human	A. Scano	University of Rome	ITA
SL-1	STS-9	28-11-83	Vestibular function and visual-vestibular interactions.	Human	R. von Baumgarten	University of Mainz	GER
SPIN-1	STS-51G	17-6-85	Sensorimotor adaptation (muscle tone, movement)	Human	A. Berthoz	CNRS (Paris)	FRA
SPIN-1	STS-51G	17-6-85	Cardiovascular data on two crew; French echocardiograph experim-ent	Human	L. Pourcelot	University of Tours	FRA
SL-D1	STS-61A	30-10-85	Cardiovascular adaptation; body impedance measurement	Human	F. Baisch	DLR Cologne	GER
SL-D1	STS-	30-10-85	Eye pressure changes	Human	J. Draeger	University of	GER

	61A		measured with a tonometer.			Hamburg	
SL-D1	STS-61A	30-10-85	Communication aspects of cognitive behaviour; gesture and speech in microgravity.	Human	A.D. Friederici	MPI, Nijmegen	NED
SL-D1	STS-61A	30-10-85	Spatial description in space: effect of perception cues on communication of spatial arrangements.	Human	A.D. Friederici	MPI, Nijmegen	NED
SL-D1	STS-61A	30-10-85	Human reactions in microgravity: reaction time (student experiment)	Human	M. Hoschek	Muehtal	GER
SL-D1	STS-61A	30-10-85	Blood displacement in upper body: central venous pressure	Human	K. Kirsch	Free University of Berlin	GER
SL-D1	STS-61A	30-10-85	Effects on cognitive behaviour: mass discrimination (also on SL-1)	Human	H.E. Ross	University of Stirling	UK
SL-D1	STS-61A	30-10-85	Vestibular research: response to optokinetic stimulation patterns (also on SL-1).	Human	R. von Baumgarten	University of Mainz	GER
D-2	STS-55	26-4-93	Peripheral & central haemodynamics adaptation to microgravity: cardiovascular reflexes.	Human	F. Bonde-Peterson	DAMEC	DAN
D-2	STS-55	26-4-93	Regulation of homeostatic volume in microgravity.	Human	R. Gerzer	Univ. of Münich (+ DLR & Univ. of Heidelberg)	GER
D-2	STS-55	26-4-93	The central venous pressure in microgravity: study at launch & in microgravity during adaptation	Human	N. Foldager	DAMEC	DAN
D-2	STS-55	26-4-93	Leg fluid distribution at rest and under LBNP: changes following dehydration, disuse, and fluid shift.	Human	F. Baisch	DLR (with TNO, Holland)	GER NED
D-2	STS-55	26-4-93	Determination of segmental fluid content and perfusion	Human	F. Baisch	DLR (with TNO, Holland & Karolinska Inst. Sweden)	GER NED SWE
D-2	STS-55	26-4-93	Cardiovascular adaptation: left ventricular function, at rest and under stimulation	Human	L. Beck	DLR(with U. of Amsterdam & Univ. of Tours)	GER NED FRA
D-2	STS-55	26-4-93	Tonometric measurement of intraocular pressure in microgravity: increase in	Human	J. Draeger	University of Hamburg	GER

			intraocular pressure, peak values, adaptation.				
D-2	STS-55	26-4-93	Tissue thickness & compliance along body axis in microgravity; new method to quantify fluid shifts within superficial tissue.	Human	K. Kirsch	Free University of Berlin	GER
D-2	STS-55	26-4-93	Cardiovascular response to LBNP and fluid loading.	Human	L. Pourcelot	University of Tours	FRA
D-2	STS-55	26-4-93	Changes in whole body nitrogen turnover rate, protein synthesis & breakdown.	Human	E.B. Fern	NESTEC Ltd, Research Centre	SUI
D-2	STS-55	26-4-93	Effects of microgravity on glucose tolerance.	Human	H.P. Maass	DLR Cologne	GER
D-2	STS-55	26-4-93	Influence of microgravity on endocrine & renal elements of volume homeostasis.	Human	P. Norsk	DAMEC	DAN
D-2	STS-55	26-4-93	Effects of space flight on pituitary-gonad-adrenalin function.	Human	I.G. Riondino	NCRA, Italy	ITA
D-2	STS-55	26-4-93	Regulation of salt balance and blood pressure: role of volume regulating hormones & plasma proteins.	Human	L. Rocker	Fed. Univ. Berlin	GER
D-2	STS-55	26-4-93	Pulmonary stratification and compartment analysis	Human	S. Groth	DAMEC	DAN
D-2	STS-55	26-4-93	Pulmonary perfusion & ventilation in microgravity	Human	D. Linnarson	Karolinska Inst.	SWE
D-2	STS-55	26-4-93	Effect of gravity on pattern of ventilation in the lung.	Human	M. Paiva	Univ. of Brussels (+Westmead Hosp., Australia, + Univ. of California)	BEL (AUSTR ALIA, USA)
D-2	STS-55	26-4-93	Dynamics of gas exchange, ventilation, & heart rate in submaximal dynamic exercise: to determine if CO_2 kinetics qualifies as a monitor of endurance performance.	Human	J. Stegemann	Deutsche Sport-Hochschule	GER
D-2	STS-55	26-4-93	Biological dosimetry	Human leucocytes	G. Obe	University of Essen	GER
D-2	STS-55	26-4-93	Personal dosimetry	Dosimeters	G. Reitz	DLR Cologne	GER
D-2	STS-55	26-4-93	Dosimetric mapping	Dosimeters	G. Reitz	DLR Cologne	GER

Details of the individual experiments which have been flown can be found in Tables 16 and 22 which, respectively, list the joint Russian/European Bion, Biocosmos and Foton series of flights, and the European experiments flown on the Shuttle.

The formal ESA Microgravity Research Programme (EMIR) is now defined within a framework of political, financial, and general research objectives. The EMIR Programme requires that, in the planning equal opportunity shall be given to the life sciences and to the materials/fluid physics sciences; with the general guideline that scientific quality shall be the final determinant when setting priorities. As far as the Life Sciences are concerned, the programme contains the general provisions outlined in the following Sections.

8.16.1 Recent and ESA life sciences experiments

IML-2. This 8 day Spacelab mission in 1994 had 18 ESA life science experiments on board (Table 23), Biorack being flown to support these, and other, experiments.

Table 23. European Experiments on board IML-2 (STS-65, 1994)

Experiment code name	Description	Principal Investigator(s) and affiliation
ADHESION	Lymphocyte activation, differentiation, and adhesion-dependence of activation.	A. Cogoli, University of Sassari
ANTIGEN	Antigen presentation and T-cell proliferation in microgravity.	A. Cogoli & G. Morrison, University of Sassari
MOTION	Lymphocyte movements and interactions (Observation in NIZEMI).	A. Cogoli & M. Cogoli, University of Sassari
PHORBOL and CYTOKINES	Effect of microgravity on cellular action: the role of cytokines.	D. Schmitt, University of Toulouse
BIOREACTOR	Effect of stirring and mixing in a bioreactor experiment in microgravity. resume	A. Cogoli & B. Bechler, ETH Weltraumbiologie, Zürich
KINETICS	Radiation repair kinetics in eukaryotes.	G. Horneck, DLR Cologne
REPAIR	Efficiency of radiation repair in prokaryotes.	G. Horneck, DLR Cologne
DROSOPHILA	Investigation of the mechanism involved in the effects of space microgravity on *Drosophila* development, behaviour and aging.	R. Marco, Independent University of Madrid
DOSIMETRY	Dosimetric mapping inside Biorack.	G. Reitz, DLR Cologne
SIGNAL	Cell microenvironment and membrane signal transduction in microgravity.	P. Bouloc, University of Paris 7
AGGREGATE	Molecular biological investigations of animal multi-cell aggregates reconstituted under microgravity.	U. Heinlein, University of Düsseldorf
MOUSE	Regulation of cell growth and differentiation by microgravity: retinoic acid-induced cell differentiation.	S. de Laat (P.Rijken), Hubrecht Laboratorium, Utrecht
RANDOM	Plant growth and random walk.	A. Johnsson, University of Trondheim
LENTIL	Effect of microgravity on lentil morphogenesis.	G. Perbal (D. Driss-Ecole), University of Paris 6
TRANSFORM	Root orientation, growth regulation, adaptation, and	T.H. Iversen, University of

	agravitropic behaviour of genetically transformed roots.	Trondheim
EGGS	The role of gravity in the establishment of embryonic axes in the amphibian embryo.	G. Ubbels, Hubrecht Laboratorium, Utrecht
URCHIN	The sea urchin larva, a potential model for studying biomineralization and demineralization processes in space.	H.J. Marthy, Laboratoire Arago, Banyuls sur Mer
BONES	The effects of microgravity on varying 1 <mult> g exposure periods on bone resorption: an *in vitro* experiment.	P. Veldhuijzen, Free University of Amsterdam

Euromir Missions. The ESA experiments for the Euromir Missions are predominantly in the life sciences - in large part due to the return capability for samples being restricted to 10 kg. Table 24 lists the experiments selected for the Euromir 94 and 95 missions.

Table 24. The ESA experiments on the Euromir 94 and 95 missions

Experiment description	Principal Investigator	Affiliation
Euromir 94		
Circadian rhythms and sleep during a 30 day mission using Oxford Medilog System SUR).	A. Gundel	DLR Flugmedizin, Cologne
Spatial orientation and space sickness.	H. Mittelstadt	MPI für Verhaltensphysiologi e Seewiesen, Germany
Adaptation of basic vestibulo-oculomotor mechanisms to altered gravity conditions (using VOG).	H. Scherer	Universitätskl., F.U. Berlin
Posture and movement, (using accelerometer camera from ALTAIR).	A. Berthoz	LPN CNRS, Paris
STAMP (Cognitive Experiment), using VIMINAL.	A. Berthoz	LPN CNRS, Paris
Otolith adaptation to different levels of gravity (ground experiment).	W. Bles	TNO Inst. for Perception, Soesterberg, Holland
Correlation of eye torsion changes with the time course of the space adaptation mechanism.	C.H. Markham	UCLA School of Medicine, Los Angeles
Non-invasive stress monitoring in space flight by hormone measurement in saliva, requiring ergometer.	C.J. Strasburger	Medizinische Klinik, Univ. Münich
Gastro-enteropancreatic peptides during zero-g and their involvement in space motion sickness.	R.L. Riepl	Medizinische Klinik, Univ. Münich
Fluid and electrolyte balance during weightlessness and possibilities of their regulation.	C. Drummer	DLR, Inst. Luft- und Raumfahrtmedizin
Fluid shifts into and out of superficial tissue stability along the body axis under microgravity in man (using ultrasonic pulse echo equipment, USD).	K.A. Kirsch	Physiology Department, Free University, Berlin
Influence of microgravity on osmo- and volume regulation in man: dynamic responses to isotonic and hypertonic loads.	P. Bie	Dept. of Medical Physiology, Univ. of Copenhagen, Denmark
Space flight related orthostatic intolerance: the role of autonomic nervous system, water balance, volume regulation hormones and energy expenditure, (requiring Russian LBNP device, ECG, haematocrit).	C. Gharib	Lab. de Physiologie de l'Environ, Lyon, France
Influence of space flight on energy metabolism and its circadian	H. Damaria Pesce	CNRS/INSERM, Inst.

variation.		Biologie, College de France, Paris
Effects of changes in central venous pressure on the erythropoietic system, under 1 <mult> g and microgravity conditions.	H.C. Gunga	Physiology Dept. Free Univ. Berlin
Central venous pressure during weightlessness.	N. Foldager	DAMEC, Univ. Hospital, Copenhagen, Denmark
Radiation health during prolonged space flight.	G. Reitz	DLR, Inst. Luft- und Raumfahrtmedizin
Magnetic resonance spectroscopy, imaging of human muscles before and after space flight (ground experiment).	J. Zange	DLR, Inst. Luft- und Raumfahrtmedizin
Changes in mechanical properties of human muscle during space flight (ground experiment).	F. Goubel	Univ. de Techn., Compiegne, France
Bone mass and structure changes and bone remodelling in space.	C. Alexandre	Lab. Biolog. du Tissu Osseux, St. Etienne, France
Euromir 95		
Influence of microgravity on renal fluid excretion in humans.	P. Norsk	DAMEC Research Righshospitalet, Copenhagen
Central venous pressure during weightlessness.	N. Foldager	DAMEC Research Righshospitalet, Copenhagen
Regulation of cardiovascular response to exercise in humans.	G. Ferretti	Fac. Medicine/Physiologie, Geneva, Switzerland
Non-invasive monitoring of drug metabolism and drug effect during prolonged weightlessness.	R. Geezer	DLR, Inst. Luft- und Raumfahrtmedizin
Differential effects of otolith input on ocular laterpulsion, cyclorotation, perceived visual vertical and ahead, and tonic neck reflexes in man.	H. Dietrich	Dept. of Neurology, Univ. of Münich
Correlation of eye torsion changes with time course of space adaptation syndrome. Binocular disconjugacy.	C.H. Markham	UCLA, School of Medicine, Los Angeles, U.S.A.
Bone mass and structure measurement during long term space flight using an ultrasound bone densitometer.	C. Alexandre	Lab. de Biologie du Tissu Osseux, Faculté de Médicine, St. Etienne, France
The application of mechanical stimulation to prevent loss of bone mass in long term space flight using simulated heel strike transients.	A. Goodship	Department of Anatomy, Univ. of Bristol, U.K.
Radiation health during prolonged space flight: environmental and personal dosimetry.	G. Reitz	DLR, Inst. Luft- und Raumfahrtmedizin
Chromosomal aberrations in peripheral lymphocytes of astronauts (ground experiment).	G. Obe	Dept. of Genetics, Univ. of Essen, Germany.
Influence of gravity on the preparation and execution of voluntary movements (ground experiment).	D.G. Ruegg	Inst. of Physiology, Univ. of Fribourg, Switzerland

Effects of short term/long term microgravity on the pulmonary gas exchange, respiratory and cardiovascular control during rest and exercise.	D. Linnarsson	Karolinska Inst. Stockholm, Sweden
Pulmonary function in microgravity.	M. Paiva	Inst. de Recherche Interdisciplinaire, Univ. Libre, Bruxelles, Belgium
Interstitial fluid balance under microgravity with special reference to pulmonary mechanics.	D. Negrini	Institute of Physiology, Univ. of Milan
Effects of microgravity on the biomechanical and bioenergetic characteristics of human skeletal muscle (ground experiment).	P. Di Prampero	Institute of Biology, University of Udine, Italy
Changes in the mechanical properties of humans during space flight (ground experiment).	F. Goubel	Univ. de Technologie, Compiegne, France
An approach to counteract impairment of musculoskeletal function in space (ground experiment).	P.A. Tesch	Dept. of Physiology, Karolinska Institute, Stockholm, Sweden
Magnetic resonance spectroscopy and imaging of human muscles and bones before and after spaceflight (ground experiment).	J. Zange	DLR, Inst. Luft- und Raumfahrtmedizin
Effect of Vitamin K supplement on bone mass during microgravity conditions.	C. Vermeer	Biochemistry Department, Univ. of Limburg, Holland
The effect of venous pressure on bone mineral density in weightlessness conditions	I.D. McCarthy	Dept. of Surgery, Hammersmith Hospital, London

Foton 10: the ESA Biopan and Biobox. The Biopan is a small multi-user experiment facility designed to support research into the combined effects of cosmic radiation, solar U.V., space vacuum, and microgravity on biological samples. It therefore serves the interests of exobiology, radiation biology, radiation physics, and dosimetry. Attached to the outside of the Foton spacecraft, the lid of the pan-shaped container is opened in space. Closure is effected prior to re-entry. Biopan first flew in October 1992, on a technical evaluation. It was originally scheduled for the first scientific mission in December, 1993, but was delayed, the Biopan-2 flight being rescheduled to September 1994 (but eventually launched on 16 February 1995). Several experiments from the first flight will be reflown on Biopan-2. Experiments recommended for Biopan-2 were as follows: *Survival of organic molecules under space conditions. Catalysis of reactions by solar UV* (A. Brack); *Radiation (HZE) induced base modifications in the cell genome* (J. Cadet); *Effects of cosmic radiation and microgravity on dormant shrimp embryos* (A. Hernandorena); *Effects of cosmic radiation on isolated organic macromolecules. Effectiveness of radioprotective drugs* (J.P. Moatti); *Relative contributions of individual components of the cosmic radiation spectrum and effectiveness of radioprotective drugs* (G. Reitz); *Exposure of bacteria and isolated DNA to solar UV, to study limits to survival and concepts for organisms on meteorites* (G. Horneck).

The Biobox is an incubator able to maintain selected temperatures between 4^{o}C and 37^{o}C, using an integral battery power supply. Limited telecommunication and telemetry facilities are available. It is designed to be accommodated within the Foton spacecraft, and first flew, with problems, on the Bion-10 mission. The experiments from that mission were reflown on Foton-10. These are as follows: *To test whether in vitro cultures of osteoblast-like cells are gravity dependant in proliferation and activity* (C. Alexandre); *The gravity* *dependence of cell differentiation in vitro of bone marrow cultures* (G. Schoeters); *Growth factor production and sensitivity and bone tissue development under gravitational stress* (J.P. Veldhuizen).

8.16.2 Spacelab facilities and flights

LMS Spacelab Mission (planned for 27 June 1996). ESA's Advanced Protein Crystallization Facility (APCF) and the Torque Velocity Dynamometer (TVD) will fly on the Life and Microgravity Spacelab (LMS) mission scheduled for launch on 27 June 1996 with a mission duration of 16 days. All facilities will be flown on a cooperative basis with NASA. The TVD is a new instrument intended for testing skeletal muscle performance and muscle disuse atrophy. It was originally developed for flight on Spacelab SLS-3, which was planned for flight in 1996 but subsequently cancelled.

Shuttle Missions to Mir (S/MM). NASA is planning at least seven Shuttle missions to the Russian Space Station Mir (see Section 8.15.1.2). Some of these missions will carry the Spacehab Module and ESA's Biorack will be accommodated in this Spacehab Module and flown on the following three missions: S/MM-03 (March 1996), S/MM-05 (December 1996) and S/MM-06 (May 1997). It is now also planned to fly the APCF on S/MM-06 (May 1997).

8.16.2.1 Biorack

Biorack is an existing multi-purpose facility, previously flown on D-1, IML-1 and IML-2, whose main components are incubators, a cooler/freezer unit, and a glovebox. It also provides special canisters for sample transport and maintenance under defined thermal conditions. Reflight refurbishment activities for the flight of Biorack on Shuttle missions to Mir are in progress. In particular, the Biorack incubators are being equipped with improved centrifuges providing variable gravitational acceleration.

8.16.2.2 Advanced Protein Crystallization Facility (APCF)

APCF is to be reflown on the USML-2 Mission (16 days duration, launch on 21 September 1995), the LMS Mission (27 June 1996) and on the Shuttle Mission to Mir S/MM-06 (May 1997). Cooperative with NASA is also anticipated for use of both APCF units on the LMS mission scheduled for flight on 27 June 1996.

8.16.2.3 Glove Box

Will be reflown on the USML-2 Spacelab Mission (21 September 1995).

8.16.2.4 Anthrorack

This human physiology research facility was originally earmarked for reflight on the E-1 mission, having previously flown on the D-2 mission (26 April to 6 May 1993). Since the E-1 mission was cancelled, the majority of hardware items of Anthrorack were placed in storage. Some items are expected to be re-used on the Neurolab Mission (26 February 1998), in modified form, to support neurophysiology experiments - being then designated EDEN (ESA Developed Elements for Neurolab). This would contain a support computer/data handling system, automated blood pressure monitor, signal processing capabilities for EMG, EOG, ECG, EEG, and dynamometer outputs, and a vestibulo-ocular interaction recording system. Initial development was completed in late November 1994. An area of major uncertainty throughout development was the scientific requirement for the Anthrorack Lower Body Negative Pressure Device (LBNPD), intended to perform micro-neurography during the application of lower body negative pressure. This is a delicate measurement, imposing design requirements which the Anthrorack LBNPD had not been built to meet. Because of the high cost of redesign it was not possible to implement the changes to the LBNPD to achieve compatibility with the micro-neurography objectives.

8.16.3 Euromir missions

8.16.3.1 Euromir 94 flight

The post mission Baseline Data Collection (BDC) programme was finalised on 16 November 1994 and transport of the BDC equipment from Star City back to Western Europe was initiated on 16 November 1994 and completed in early February 1995. The life science samples (blood samples, etc.) from pre- and post-mission BDC and flight were stored under controlled conditions at Star City and transported (hand-carried) to DLR in Germany around 20 November 1994 where they were put into further storage. Distribution of the samples to investigators started early 1995.

8.16.3.2 Euromir 95

Selection of experiments for Euromir 95 was based, in part, on the mass allocation for orbital transfer (105 kg up and 5 kg down). Excess return mass may be returned via Shuttle missions to Mir instead of the Russian Soyuz vehicle. Another consideration in experiment choice and design is that experiments depend on availability of astronaut time. For the whole Euromir 95 payload, 405 h from the ESA astronaut are available, 210 h being set aside for life science experiments. Crew time involvement in experiments needs to be subjected to detailed assessment .

ESA Microgravity multi-user facilities which are planned to be used on the Euromir 95 mission in the framework of the EMIR-1 Programme include the Respiratory Gas Analyzer, also referred to as RMS-II; the Bone Densitometer (BDM) and the Freezer. The Respiratory Gas Analyzer is a new instrument is based on an opto-acoustic, excitation/detection system, which has comparable sensitivity for many gases to the mass spectrometer, but a substantially smaller mass/volume and power requirement, and it does not require a vacuum. Although problems have been encountered with the operating system software, the schedule for crew training, science verification and flight qualification has been maintained. Integration of all models of the Bone Densitometer was completed on schedule. The freezer for Euromir 95, which is an inflatable unit, has been newly developed for this mission.

8.16.4 Mini-missions

There will continue to be a programme of short duration low-gravity experiments based upon sounding rockets, aircraft parabolic flights, and drop towers, since they have proven to be of value for exploratory work and equipment testing.

Sounding rockets, in particular, have played a significant role in microgravity experimentation. Table 25 shows the range of Life Sciences rocket borne experiments which have been carried out through the years by ESA and individual Member States, using the Texus and Maser rockets. The longer microgravity duration (14 min.) and larger payload (440 kg) available with the new MAXUS rocket may further increase the usefulness of these systems.

Table 25 (Left). European sounding rocket biology experiments (to 1993)

[This table is a double page spread; the right-hand pages start on p. 85. To see the complete entry, note the row number and follow it to the right-hand page below]

Row No.	Flight	Launch	Discipline	Topic	Title	Species
1	Texus 11	27 Apr 85	Cell biology	Cell electrofusion	Electrofusion of yeast cells	Yeast

2	Texus 13	30 Apr 86	Cell biology	Cell electrofusion	Electrofusion of yeast cells	Yeast
3	Texus 13	30 Apr 86	Cell biology	Cell electrofusion	Electrofusion of plant cells	Tobacco
4	Texus 13	30 Apr 86	Cell biology	Cell electrofusion	Electrofusion of plant cells	Oat
5	Texus 14B	03 May 87	Cell biology	Cell electrofusion	Fusion of yeast cells	Yeast
6	Texus 14B	03 May 87	Cell biology	Transfection (gene transfer)	Electric field induced gene transfer	Human
7	Texus 17	02 May 88	Cell biology	Cell electrofusion	Electrofusion of plant cells	Tobacco
8	Texus 17	02 May 88	Developmental biology	Fertilisation and embryo polarity	Amphibian embryo	Clawed toad
9	Texus 18	06 May 88	Botany	Graviperception (cell structure)	Cress germination	Garden cress
10	Texus 18	06 May 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Rabbit
11	Texus 18	06 May 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Rat
12	Texus 18	06 May 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Guinea Pig
13	Texus 18	06 May 88	Cell biology	Cell electrofusion	Electrofusion of yeast cells	Yeast
14	Texus 18	06 May 88	Cell biology	Transfection (gene transfer)	Electric field induced gene Transfer	Human
15	Texus 19	28 Nov 88	Botany	Graviperception (cell structure)	Cress germination	Garden cress
16	Texus 19	28 Nov 88	Zoology	Motility	Motility of bull spermatozoa	Bull
17	Texus 20	02 Dec 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Rabbit
18	Texus 20	02 Dec 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Rat
19	Texus 20	02 Dec 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Guinea pig
20	Texus 20	02 Dec 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Chicken
21	Texus 20	02 Dec 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Human
22	Texus 20	02 Dec 88	Technology	Electrophoresis (FFE)	Electrophoretic separation	Cattle
23	Texus 20	02 Dec 88	Technology	Electrophoresis (FFE)	Electrophoretic Separation	Mouse
24	Maser 3	10 Apr 89	Development biology	Fertilisation and embryo polarity	Dorsoventral axis development	Clawed toad
25	Maser 3	10 Apr 89	Botany	Membrane functions	During sexual reproduction	
26	Maser 3	10 Apr 89	Cell biology	Membrane and metabolism	Cell growth and differentiation	Human
27	Maser 3	10 Apr 89	Cell biology	Membrane functions	Membrane binding of Concanavalin A	Human

28	Texus 21	30 Apr 89	Cell biology	Cell electrofusion	Electrofusion of plant protoplasts	Tobacco
29	Texus 21	30 Ape 89	Botany	Graviperception (cell structure)	Protoplasm streaming in *Chara* rhizoids	
30	Texus 22	03 May 89	Cell biology	Cell electrofusion	Electrofusion of yeast cells	Yeast
31	Texus 22	03 May 89	Cell biology	Transfection (gene transfer)	Electric field induced gene transfer	Human
32	Texus 23	25 Nov 89	Botany	Graviperception (cell structure)	Cress germination	Garden cress
33	Texus 24	25 Nov 89	Botany	Graviperception (orientation)	Mobility of *Euglena*	
34	Texus 24	06 Dec 89	Cell biology	Electrophoresis (FFE)	Electrophoretic separation	
35	Maser 4	29 Mar 90	Cell biology	Membrane and metabolism	Lymphocytes in microgravity	Human
36	Maser 4	29 Mar 90	Developmental biology	Fertilisation and embryo polarity	Fertilisation of sea urchin eggs	Sea urchin
37	Maser 4	29 Mar 90	Cell biology	Membrane and metabolism	Regulation of cell growth and differentiation	Human
38	Maser 4	29 Mar 90	Cell biology	Membrane and metabolism	Regulation of cell growth and differentiation	Human
39	Maser 4	29 Mar 90	Technology	Electrophoresis (CFE)	Electrophoretic orientation of DNA molecules	
40	Texus 25	13 May 90	Botany	Graviperception (cell structure)	Statolith function in *Chara* rhizoids	
41	Texus 25	13 May 90	Cell biology	Cell electrofusion	Electrofusion of plant protoplasts	Tobacco
42	Texus 26	15 May 90	Zoology	Motility	Motility of spermatozoa	Bull
43	Texus 26	15 May 90	Cell biology	Cell electrofusion	Electrofusion of animal cells	Human
44	Texus 27	15 Nov 90	Technology	Electrophoresis (CFE)	Electrophoresis visualisation EXP2 (haemoglobin)	Bull
45	Texus 27	15 Nov 90	Microbiology	Graviperception (Orientation)	Role of gravity for the spatial orientation of cells	
46	Texus 28	23 Nov 91	Technology	Electrophoresis (CFE)	Electrophoresis visualisation EXP2 (haemoglobin)	Bull
47	Texus 28	23 Nov 91	Botany	Graviperception (cell structure)	*Chara* cytoskeleton	
48	Texus 28	23 Nov 91	Botany	Graviperception (orientation)	Gravitaxis and phototaxis in flagellates	
49	Texus 28	23 Nov 91	Microbiology	Graviperception (orientation)	Role of gravity for the spatial orientation of cells	
50	Maser 5	09 Apr 92	Cell biology	Cell electrofusion	Cell fusion	Human
51	Maser 5	09 Apr 92	Cell biology	Membrane functions	Responses to protein kinase C signal transduction	Human
52	Maser 5	09 Apr 92	Developmental biology	Fertilisation and embryo polarity	Fertilisation of sea urchin eggs	Sea urchin

53	Texus 29	05 Sep 92	Botany	Graviperception (orientation)	Gravitaxis and phototaxis in flagellates	
54	Texus 29	05 Sep 92	Botany	Graviperception (cell structure)	Cytoplasm streaming in *Chara* rhizoids	
55	Maxus 1B	08 Nov 92	Cell biology	Membrane and metabolism	Lymphocytes in microgravity	Human
56	Maxus 1B	08 Nov 92	Technology	Electrophoresis (CFE)	Electrophoretic orientation experiment (DNA)	
57	Texus 30	01 May 93	Cell biology	Cell metabolism	Protein pattern in mesophyll protoplasts	
58	Texus 30	01 May 93	Cell biology	Cell metabolism	Gravitation and energy metabolism of plant cells	Tobacco
59	Texus 30	01 May 93	Botany	Graviperception (orientation)	Gravitaxis and phototaxis in flagellates	
60	Texus 30	01 May 93	Botany	Graviperception (cell	Cytoplasm streaming in *Chara* rhizoids	

Table 25 (Right). European sounding rocket biology experiments (to 1993)

Row No.	Specific name	Category	Cell type	Key hardware	Investigator	Affiliation	Country
1	*Saccharomyces sp.*	Fungus	Free living	TEM 06-5	U. Zimmermann	University Wurzburg	GER
2	*Saccharomyces sp.*	Fungus	Free living	TEM 06-5	U. Zimmermann	University Wurzburg	GER
3	*Nicotiana tabacum*	Plant cells	Leaf cells	TEM 06-5	R. Hampp	University Tübingen	GER
4	*Avena sativa*	Plant cells	Leaf cells	TEM 06-5	R. Hampp	University Tübingen	GER
5	*Saccharomyces cerevisiae*	Fungus	Free living	TEM 06-11	U. Zimmermann	University Wurzburg	GER
6	*Homo sapiens sapiens*	Mammal cells	Lymphocytes	TEM 06-11	U. Zimmermann	University Wurzburg	GER
7	*Nicotiana tabacum*	Plant cells	Isolated	TEM 06-5	R. Hampp	University Tübingen	GER
8	*Xenopus laevis*	Amphibian		TEM 06-15	G. Ubbeis	Hubrecht Laboratory Utrecht	NED
9	*Lepidium sativum*	Plants		TEM KT	D. Volkmann	University Bonn	GER
10		Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
11	*Rattus rattus*	Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
12		Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
13	*Saccharomyces cerevisiae*	Fungus	Free living	TEM 06-11	U. Zimmermann	University Wurzburg	GER
14	*Homo sapiens sapiens*	Mammal cells	Lymphocytes	TEM 06-11	U. Zimmermann	University Wurzburg	GER
15	*Lepidium sativum*	Plants		TEM KT	D. Volkmann	University Bonn	GER
16		Mammal cells	Spermatozoa	TEM 06-5	U. Engelmann	University Münich	GER

17		Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
18	*Rattus rattus*	Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
19		Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
20	*Gallus domesticus*	Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
21	*Homo sapiens sapiens*	Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
22		Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
23		Mammal cells	Erythrocytes	TEM 06-13	K. Hanning	MPI Martinsried	GER
24	*Xenopus laevis*	Amphibian (E)		TEM 06-15	G. Ubbeis	Hubrecht Laboratory Utrecht	NED
25	*Chlamydomonas sp.*	Algae	Free living	CIS-1	P. Van den Ende	University Amsterdam	NED
26	*Homo sapiens sapiens*	Mammal cells	A431 Carcinoma	CIS -1	S.W. De Laat	Hubrecht Laboratory Utrecht	NED
27	*Homo sapiens sapiens*	Mammal cells	Lymphocytes	CIS-1	A. Cogoli	ETH Zürich	SUI
28	*Nicotiana tabacum*	Plant cells	Isolated	TEM 06-5	R. Hammp	University Tübingen	GER
29	*Chara sp.*	Algae		TEM 06-16	A. Sievers	University Bonn	GER
30	*Saccharomyces cerevisiae*	Fungus	Free living	TEM 06-11	U. Zimmermann	University Wurzburg	GER
31	*Homo sapiens sapiens*	Mammal cells	Lymphocytes	TEM 06-11	U. Zimmermann	University Wurzburg	GER
32	*Lepidium sativum*	Plant		TEM BIO	D. Volkmann	University Bonn	GER
33	*Euglena sp.*	Algae	Free living	TEM 06-19	D.P. Haeder	University Erlangen	GER
34		Mammal cells	Erythrocytes	TEM 04-1 (06-13)	K. Hanning	MPI Martinsried	GER
35	*Homo sapiens sapiens*	Mammal cells	Lymphocytes	CIS-2	A. Cogoli	ETH Zürich	SUI
36	*Paracentrotus lividus*	Echinoderm		CIS-2	H.J. Marthy	Lab Arago/University Paris Curie	FRA
37	*Homo sapiens sapiens*	Mammal cells	A431 Carcinoma	CIS-2	S.W. De Laat	Hubrecht Laboratory Utrecht	NED
38	*Homo sapiens sapiens*	Mammal cells	A431 Carcinoma	CIS-2	A. Verkleij	State University Utrecht	NED
39	*n.a.*	macro-molecules		CIS-2	B. Norden	Chalmers University Gothenburg	SWE
40	*Chara sp.*	Algae		TEM 06-16	A. Sievers	University Bonn	GER
41	*Nicotiana tabacum*	Plant cells	Isolated	TEM 06-5	R. Hampp	University Tübingen	GER
42		Mammal cells	Spermatozoa	TEM 06-19	P. Schill	University Giessen	GER
43	*Homo sapiens sapiens*	Mammal cells	Lymphocytes	TEM 06-11	U. Zimmermann	University Wurzburg	GER
44		macro-		TEM04-2	H. Balman	University Toulouse	FRA

		molecules					
45	*Paramecium spec*	Protozoa (Ciliates)	Free living	TEM 06-19	R. Hemmersbach-Krause	DLR Cologne	GER
46		macro-molecules		TEM04-2	H. Balman	University Toulouse	FRA
47	*Chara sp.*	Algae		TEM 06-16	A. Sievers	University Bonn	GER
48	*Euglena gracilis*	Algae	Free Living	TEM 06-5	D.P. Haeder	University Erlangen	GER
49	*Paramecium sp.*	Protozoa (Ciliates)	Free living	TEM 06-5	R. Hemmersbach-Krause	DLR Cologne	GER
50	*Homo sapiens sapiens*	Mammal cells	Fibroblasts	CIS-3	A. Cogoli	ETH Zürich	SUI
51	*Homo sapiens sapiens*	Mammal cells	A431 Carcinoma	CIS-3	S.W. De Laat	Hubrecht Laboratory Utrecht	NED
52	*Paracentrotus lividus*	Echinoderm		CIS-3	H.J. Marthy	Lab Arago/University Paris Curie	FRA
53	*Euglena gracilis*	Algae	Free living	TEM 06-5	D.P. Haeder	University Erlangen	GER
54	*Chara sp.*	Algae		TEM 06-5	A. Sievers	University Bonn	GER
55	*Homo sapiens sapiens*	mammal cells	Lymphocytes	TEM 06-5M	A. Cogoli	ETH Zürich	SUI
56	*n.a.*	macro-molecules		MEO	B. Norden	Chalmers University Gothenburg	SWE
57	*Vicia faba*	Plant cells	Mesophyll	TEM 06-21	H. Schnabel	University Bonn	GER
58	*Nicotiana tabacum*	Plant cells	Isolated	TEM 06-21	R. Hampp	University Tübingen	GER

Parabolic aircraft flights have been used recently for precursor experiments, for equipment checkout, and for experiment optimization in the life sciences. They have also been used for the study of the ‘instantaneous’ physiological reactions of humans to transient changes in gravitational acceleration, as it cycles from about $10^{-2} \times g$ through to some $2 \times g$. Consequently a continuing programme of activity, amounting to two campaigns, each of 90 parabolas of 20 seconds duration, per year is planned for such research.

8.17 Conclusions

Particularly for the European nations, the flight opportunities in the past have been very restricted; indeed, they still are. For the scientists, this lack of continuity of experimentation has, previously, often been combined with limited facilities for controls or *in situ* analysis. Evidently, the transition from exploratory research to a programme of rigorous, in-depth research on a frequent routine basis, has yet to be made for many subject areas. Perhaps that is the principal change yet to be made, and something upon which effort should now be focused.

Three other general conclusions can also be made from this survey. First, it is clear that ESA member states have established a solid and competitive position in all of the main life science research fields. It is especially true in the space biology area. That position is likely to be maintained, provided a facility of the quality of the Spacelab can be flown on a regular basis, so as to afford frequent follow-up experiments, adequate controls, and the necessary sample handling and preservation facilities.

Second, it seems to be that the area of musculo-skeletal studies has received relatively limited attention. Interest in the earlier flights has naturally centred on the immediate and short term effects of microgravity, on the cardiovascular and the neuro-vestibular research areas. That situation is obviously changing, with the reality of long duration missions, but evidently there is much still to be done in the musculo-skeletal research field. The problem for ESA will be to provide for the necessary controlled experimentation on long duration missions on a routine basis during the next few years.

Third, it is seen that the field of biotechnology research has been strongly emphasized in the outline of the future Russian programme, with considerable interest in such research also being expressed by NASA. By contrast, ESA has not emphasized this research area, as far as space experiments are concerned. Neither do the ESA Member States appear to have developed much interest in this topic, with the exception of Germany. In so far as the closed bioregenerative life support system developments fall within this heading, it would be surprising if that research were not to be strongly pursued by the principals in the Space Station programme in the future. NASA official policy in space life science research follows from a commitment to the long term goal of extended manned space missions. With that objective in mind, much of the NASA research programme concentrates on human physiology, with supporting studies down to the cellular level in biology. That relative emphasis looks set to continue.

It is interesting to note in passing that, as part of its longer term strategy, NASA has signed a cooperative agreement with the U.S. National Institutes of Health. That agreement is significant, for it recognizes and formalizes the essential link between the space and ground based life science research. It is intended to bring the NASA life science space research work more readily within the critical purview of the NIH researchers, whilst at the same time encouraging the exchange of information and personnel between the two domains.

To conclude then, it is clear that ESA and the Member States have established a very good research record in space life sciences research, and must be commended for having achieved so much, despite so many practical constraints. The future for the ESA Life Sciences programme must surely lie in exploiting vigorously these current strengths.