Microgravity Effects on Standardized Cognitive Performance Measures

Principal Investigator: Dr. S. G. Schiflett

Commander Col. Robert D. Cabana (USMC) uses a laptop computer to record responses to PAWS rotated images, spatial patterns, and questions regarding number and letter sequences and mathematical calculations. These and other tests are used to determine his cognitive functioning in the spaceflight environment.

Present-day space travelers are subject to a variety of stresses during space flight. These include microgravity, physical isolation, confinement, lack of privacy, fatigue, and changing work/rest cycles. On Earth, both fatigue and changing work/rest cycles degrade cognitive performance and productivity. The purpose of this experiment is to determine the effects of microgravity upon cognitive skills critical to the success of operational tasks in space. The principal objective is to distinguish between the effects of microgravity upon specific information processing skills affecting performance and those of fatigue caused by long work periods or shifts in the work/rest cycle.

To measure cognitive skills, the investigators use a set of six computerized cognitive performance tests taken from the Unified Tri-Service Cognitive Performance Assessment Battery. This series of tests is internationally recognized and has proven sensitive to many environmental stressors. The battery of six tests selected for space is called the Performance Assessment Workstation (PAWS). The tests are based on current theoretical models of human performance. They were selected by analyzing tasks related to space missions and for their hypothesized sensitivity to microgravity. Multiple subjective measures of cumulative fatigue and changing mood states are also included in PAWS for interpreting performance data.

The astronauts will achieve stable, reliable performance baselines through several practice sessions before launch. While in orbit, the effects of microgravity will be assessed daily. After the astronauts return to Earth, data will be collected to determine the rate of recovery of any detrimental effects of microgravity on cognitive information processing. By comparing their performance in space and on Earth, the investigators will quantify the effects of space flight on each of the cognitive skills measured.

The performance tests will be presented to the astronauts on a laptop computer. The computer records the speed and accuracy of the astronaut's responses to rotated images, letter sequences, math calculations, spatial patterns, and recollection of numbers. It also records the astronaut's ability to track an unstable object on the computer screen using a precision trackball. Perhaps the most challenging test for the astronaut will be to do two things at one time and rapidly switch attention between the two tasks. A combination of this dual task is included in the PAWS test battery.

Since astronauts are involved in many activities, PAWS practice may be disrupted during the training period. Also, the launch could be delayed for several hours or days. Because of these potential disruptions and delays, the investigators were concerned that the preflight baseline calibration for each astronaut would not be reliable. Their ground-based, scientific support studies have determined, for the specific practice schedules tested, that baseline performance will be reliable as long as subjects complete the minimum required number of sessions before flight. This important finding allowed them to accommodate the very busy training/preflight schedule of the astronauts and continue to have confidence in the reliability, stability, and sensitivity of the PAWS tests.

As technology takes us physically and mentally farther away from the evolutionary environment of Earth, humans will be exposed to a variety of conditions that may cause their performance to deteriorate. PAWS provides scientists a tool to assess cognitive performance and, thus, measure the impact of new and unknown stressors. While measurement of performance is only the first step toward understanding the effects of spaceflight on cognitive functioning, it also allows space scientists to quantify any problem so that specific solutions can be developed to counteract any loss of productivity. The PAWS results will provide information to help planners schedule astronauts' work under a variety of cognitively degraded conditions. Thus, the experiment may help to maximize productivity and job satisfaction in astronauts who will live for extended periods of time in the Space Station and beyond. ●

SECOND INTERNATIONAL MICROGRAVITY LABORATORY

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During IML-2, experiments will be performed inside Spacelab, a modular laboratory developed by the European Space Agency for NASA's Space Shuttle program.

A UNIQUE LABORATORY IN SPACE

An international team of experts is working together to study basic scientific issues that can only be explored in space. They are participating in the National Aeronautics and Space Administration's (NASA's) Second International Microgravity Laboratory (IML-2) mission. Through the mission's global approach to space science, the international partners share the costs of developing equipment and supporting investigators, thus reducing the expenses to any one space agency. Scientists from around the world will use the IML-2 equipment to conduct complementary investigations and focus efforts on fundamental questions of interest to the worldwide scientific community.

The IML-2 mission, managed by NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, is laying the groundwork for broader international partnerships and scientific alliances that will continue during future global endeavors. Five other space agencies have joined NASA on this mission: the Canadian Space Agency (CSA), the European Space Agency (ESA), the French Space Agency (CNES), the German Space Agency (DARA), and the National Space Development Agency of Japan (NASDA). During the mission, hundreds of scientists and engineers from the countries represented by these agencies will gather at the MSFC Payload Operations Control Center (POCC), where they can coordinate their experiments with their colleagues and communicate with the space crew performing experiment operations.

Members of the international community of scientists in the Science Operations Area at NASA's Marshall Space Flight Center applaud the culmination of years of planning and preparation as IML-1 launches. During the IML-2 mission, scientists from around the world will again work in the Science Operations Area. From here they can monitor experiments via video and voice links to the Shuttle, send commands to their instruments, and even discuss experiment operations with the crew in space.

For IML-2, microgravity and life sciences investigations will be conducted inside Spacelab, a special laboratory that fits in the Space Shuttle payload bay. As the Shuttle orbits Earth, it provides a nearly weightless, or microgravity, environment. Microgravity cannot be duplicated with Earth-based facilities for longer than a few minutes. The IML-2 mission objective is to conduct microgravity and life sciences investigations that require this unique low-gravity environment created inside an orbiting space laboratory free-falling around Earth.

In a space laboratory, some of the physical processes that affect experiments are not as dominant as they are on Earth. In ground laboratories, gravity-related disturbances such as convection, buoyancy, sedimentation, and hydrostatic pressure not only can limit the quality of some materials but also can restrict the parameters that can be studied. By carrying out experiments in microgravity, effects caused by gravity-driven phenomena may be reduced, and it is easier to examine aspects of the material that are difficult to study on Earth. This makes it possible to learn more about the intrinsic properties of materials.

Hundreds of people support the IML-2 mission on the ground, working in the Payload Operations Control Center at MSFC and at the Mission Control Center at JSC.

IML-2 scientists will use furnaces and other facilities to produce a variety of material structures from crystals to metal alloys. They will examine how bubble formation and migration, surface-tension forces, thermal gradients, and other parameters affect material development in microgravity. Samples produced in space will be compared with similar samples made on Earth during and after the mission. Scientists will also be able to study fluid processes, such as thermocapillary flows and critical-point phase transitions, that are masked or distorted on Earth. Nearly every physical science depends on an understanding of these basic mechanisms, and this knowledge may help us develop the next generation of materials needed for high-tech applications.

Life sciences research inside Spacelab will help reveal the role of gravity in shaping life as we know it and show us how living organisms react and adapt to microgravity. Before we make space our second home, we must know how living things from Earth are affected by reduced gravity and increased radiation in the space environment. This knowledge is crucial if people are to live and work safely and productively in space.

To examine the adaptation of the human body to microgravity, the IML-2 payload crew will conduct experiments on themselves, studying changes in the shapes of their spines and the adaptation of their hearts and circulatory systems to microgravity. Investigators will use biological specimens — ranging from cells to whole organisms — to define the effects of microgravity and radiation on physiology, growth patterns, genetic material, bone development, and cell differentiation and reproduction.

Microgravity science and life sciences, the IML-2 disciplines, are exciting areas of research because discoveries in these fields have the potential to greatly enhance the quality of life on Earth through applications and spinoffs. For example, if the structures of certain proteins can be determined by examining high-quality protein crystals grown in microgravity, not only will we learn about an essential component of all life forms, but we may also be able to use this knowledge to improve the medical treatment of many diseases. Learning about the influence of gravity on physical phenomena will be useful in producing materials on the ground and perhaps eventually in space. Experiments may lead to refinements of materials such as semiconductors, superconductors, and exotic ceramics and glasses.

Many of the IML-2 experiments owe their heritage to earlier Skylab, sounding rocket, and ground-based experiments, and some have evolved over several Spacelab missions. Facilities flown on previous missions are being used again to probe new scientific questions or to expand upon prior studies. IML-2 scientists are exploring the unknown by conducting a series of observations that may confirm or disprove their theories. It is a challenging enterprise because ideas must be formulated, tested by experiments, and ultimately be retested, revised, or discarded. The most promising experiments will not end with an answer but with a host of new, unanticipated questions. ●

Steps to Mission Success

IML-2 depends as much on successful management and planning as it does on science and technology.

Preflight

To maximize the science obtained in space, many years are spent in careful preparation and training. A team of NASA managers, scientists, engineers, technicians, and contractors work together to plan, organize, develop, and implement the IML-2 mission. NASA defines the program and science goals, selects experiments through a peer review process, and identifies the principal investigators, the lead scientists for each investigation. For IML-2, agreements were made with international partners who develop flight hardware and support investigators from their countries. Investigators from the United States have also been selected to perform complementary experiments in facilities developed by other countries.

One of NASA's field centers, the Marshall Space Flight Center in Huntsville, Alabama, manages the IML-2 mission. The mission management team controls mission development and integration, supervises payload crew training and ground support team training, and devises a very detailed and specific mission timeline, the minute-by-minute master schedule for inflight activities. The MSFC management team interacts closely with the principal investigators to guarantee that the hardware meets their scientific requirements. An Investigator Working Group addresses science issues periodically, explores ways to share data, suggests how to divide Spacelab resources, and helps select and train the payload crew. The mission management team is responsible for training the crew in science operations and preparing the investigators for working in the ground control center during the mission.

Other NASA centers are crucial to ensuring the launch and operation of the IML-2 mission. The Space Shuttle and Spacelab are prepared and launched at the Kennedy Space Center (KSC) in Cape Canaveral, Florida. Before launch, Kennedy personnel use a blueprint designed by the Marshall management team to install the experiments into the Spacelab and the orbiter middeck and load Spacelab into the Shuttle payload bay.

Inflight

After launch, the Mission Control Center at the Johnson Space Center (JSC) in Houston, Texas, controls the Shuttle flight until landing, continually directing and monitoring the progress of orbiter flight operations. The mission management team works in the Payload Operations Control Center at MSFC. Digital data, video, and voice communications from the Space Shuttle keep the team apprised of science operations so that they can monitor and direct Spacelab operations. The Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, maintains the ground-to-Shuttle and Shuttle-to-ground communications through a network of satellites and ground-based relay stations and records data from experiments. The principal investigators also work in the POCC's Science Operations Area, following the progress of their experiments and instructing the crew or sending computer commands directly to Spacelab experiment equipment. Some investigators work at KSC doing ground control experiments that are similar to experiments taking place in orbit.

When the Shuttle reaches orbit, the payload crewmembers activate Spacelab life support systems and then open the airlock and float from the Shuttle middeck through a tunnel into Spacelab. Soon, they begin to set up equipment and turn on experiment facilities. Specimens and containers are transferred from middeck stowage to the laboratory. For the rest of the mission, experiments proceed according to the preplanned master timeline, with adjustments made for unexpected opportunities. Just before landing, the crew deactivates equipment and stows samples.

Postflight

After landing, many experiment samples, some of which have limited lifetimes, are returned to the scientists for evaluation. Later, experiment hardware is also returned to the space agency that developed it. Computer tapes, voice recordings, video tapes, and other data are organized and forwarded to investigators. Analysis of the data starts even before the Shuttle touches down and may continue for several years.

SCIENCE OVERVIEW

IML-2 consists of approximately 80 investigations, half microgravity science and half life sciences. The investigations are grouped in the following scientific areas:

Materials Science: An isothermal furnace and a facility that has an electromagnetic device for positioning samples are both used to conduct experiments on a variety of metals and alloys.

Fluid Science: One facility studies the interfacial processes of bubbles, drops, and particles in microgravity, and another studies fluids at their critical points.

Microgravity Environment and Countermeasure: Two experiments characterize the magnitude and frequency of accelerations that affect microgravity experiments, and one tests a method for counteracting the effects of accelerations.

Bioprocessing: One facility is used to produce a variety of protein crystals, and two other facilities use electrophoresis to separate biological substances.

Space Biology: Four facilities with features such as microscopes and centrifuges are used to observe the effects of microgravity on biological specimens ranging from whole organisms, such as fish and plants, to single cells of a variety of animals and plants.

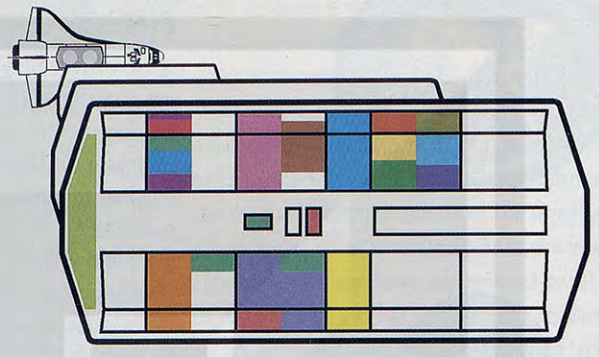
Human Physiology: One investigation uses a battery of tests to examine how the spine changes in microgravity, and another group of experiments studies the effects of extended duration missions on humans and performs countermeasures to decrease negative cardiovascular responses that occur upon return to 1-g.

Radiation Biology: Two facilities make precise measurements of the radiation environment inside Spacelab and test methods that may be used for space radiation forecasting aboard future spacecraft.

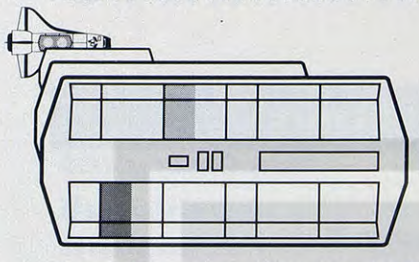
The IML-2 Instruments and Their Heritage

Important scientific questions are not answered with one experiment. Often scientific inquiries span the lifetime of a scientist or are continued by several generations of scientists. Many of the IML-2 hypotheses are based on results from earlier spaceflight experiments on Skylab, our first space station, or during the decade of Spacelab flights that began in 1983 with Spacelab 1. Some of the IML-2 facilities or precursor instruments used to develop IML-2 hardware have flown on the following Spacelab missions: Spacelab 1 (SL-1), German Spacelab D-1 (SL-D1), First Spacelab Life Sciences (SLS-1), First International Microgravity Laboratory (IML-1), First United States Microgravity Laboratory (USML-1), Japanese Spacelab J (SL-J), and First United States Microgravity Payload (USMP-1). The investigations have also been supported by years of ground-based research and experiments aboard rockets and aircraft that simulate microgravity for brief periods.

IML-2 Facilities



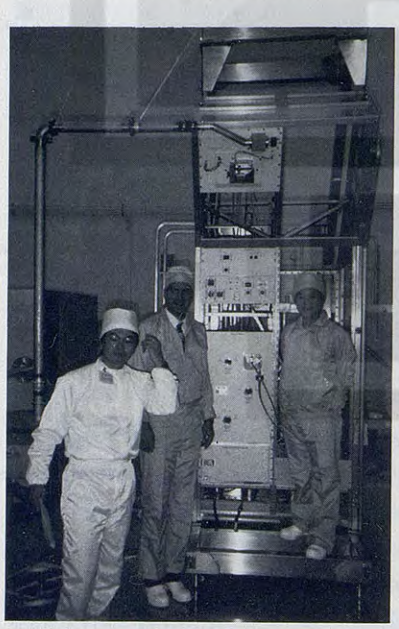
Scientific Instrument	Flight Status
Materials Science	
• Large Isothermal Furnace (LIF)	Precursor on SL-J
• Electromagnetic Containerless Processing Facility (TEMPUS)	1st flight
Fluid Science	
• Bubble, Drop, and Particle Unit (BDPU)	1st flight
• Critical Point Facility (CPF)	IML-1
Microgravity Environment and Countermeasure	
• Space Acceleration Measurement System (SAMS)	SLS-1, IML-1, USML-1, SL-J, USMP-1
• Quasi-Steady Acceleration Measurement System (QSAM)	1st flight
• Vibration Isolation Box Experiment System (VIBES)	1st flight
Bioprocessing	
• Advanced Protein Crystallization Facility (APCF)	Spacehab
• Free-Flow Electrophoresis Unit (FFEU)	SL-J
• Applied Research on Separation Methods Using Space Electrophoresis (RAMSES)	1st flight
Space Biology	
• Aquatic Animal Experiment Unit (AAEU)	Precursor on SL-J
• Biorack (BR)	SL-D1, IML-1
• Slow Rotating Centrifuge Microscope (NIZEMI)	1st flight
• Thermoelectric Incubator (TEI)/Cell Culture Kits (CCK)	Precursor on SL-J
Human Physiology	
• Extended Duration Orbiter Medical Project (EDOMP)	USML-1, SL-J
• Spinal Changes in Microgravity (SCM)	Precursor on IML-1
Radiation Biology	
• Biostack (BSK)	SL-1, SL-D1, IML-1
• Real-Time Radiation Monitoring Device (RRMD)	1st flight



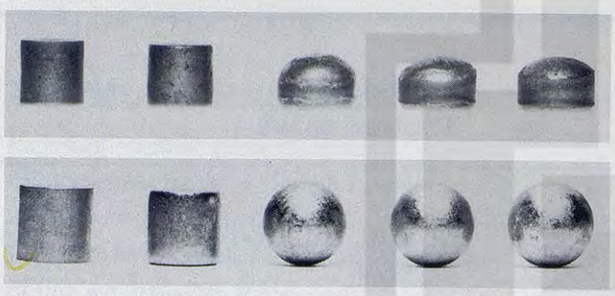
Large Isothermal Furnace (LIF)

Payload Developer: NASDA

This furnace heats large samples uniformly at a maximum temperature of 1600 °C. Eight samples were processed successfully during the Spacelab J mission and are being analyzed by investigators; five samples are scheduled to be solidified under various temperature profiles on IML-2. The furnace consists of a sample cartridge and a heating element surrounded by a vacuum chamber. A crewmember inserts a sample cartridge into the furnace, and then the experiment operations are controlled automatically by computer. At the end of the experiment, the sample is cooled by a water jacket and/or by a continuous flow of helium through the furnace, which will cool samples rapidly.



The LIF facility



The top row of tungsten (W) - nickel (Ni) samples was sintered at 1450 °C for 60 minutes on Earth; the bottom row was sintered in the LIF at 1450 °C for 60 minutes during the Spacelab-J mission. When the percentage of nickel in the specimen increases, the sample tends to behave like a liquid, resulting in the spherical configuration in space.

Gravitational Role in Liquid Phase Sintering

Principal Investigator: Dr. R.M. German

This experiment will determine the influence of gravity on the macrostructural and microstructural changes of heavy alloy tungsten-nickel-iron systems. The material will be heated so that the iron and nickel form a liquid, surrounding the uniformly dispersed tungsten. This process, called liquid phase sintering, is used to produce alloys of novel composition. For example, the density differences between the tungsten and iron-nickel liquid that forms at 1500 °C prevent the fabrication of this alloy by processes other than sintering. This investigation will add to ground-based research, which indicates that gravity plays a role in distorting the microstructure of samples sintered on Earth. Seven tungsten heavy alloy composites in one cartridge will be sintered at 1500 °C for three heating periods (1, 15, and 120 minutes). The samples, as well as thermal and acceleration data, will be analyzed postflight.

Mixing of a Melt of Multicomponent Compound Semiconductor

Principal Investigator: Dr. A. Hirata

This investigation will develop a new technique for uniformly mixing the melt of compound semiconductors. Semiconductors are made of several components with different densities. On Earth, gravity separates them by density differences. In space, it may be possible to mix these components more uniformly and faster using Marangoni convection, flow driven by an interfacial tension gradient caused by concentration differences on the free interface of the melt. This will result in a semiconductor with more uniform content, which will allow it to transmit electrons more efficiently in computers and other electronic devices.

Two kinds of solid material comprised of three pure constituents are melted and solidified to form compound semiconductors of indium-gallium-antimony (InGaSb). Four samples will be processed using Marangoni convection to mix the sample. Two samples will be processed using only molecular diffusion to mix the components. The solidified crystals will be compared postflight to determine crystal quality, crystal shape, size of crystal particulates, and the effects of Marangoni convection and molecular diffusion on mixing of the melt and on uniformity of the multicomponent compound semiconductor.

Effect of Weightlessness on Microstructure and Strength of Ordered TiAl Intermetallic Alloys

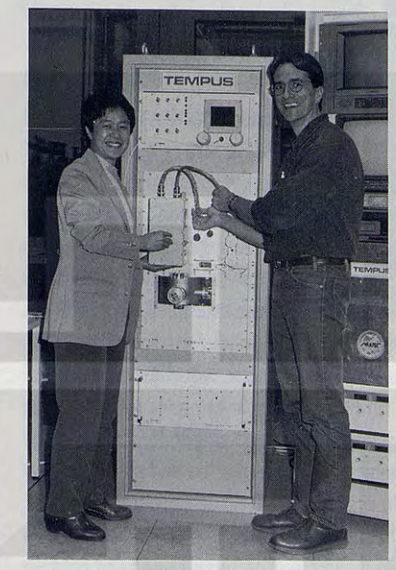
Principal Investigator: Dr. M. Takeyama

Ceramic particles of titanium-diboride (TiB_2) will be added to metallic alloys of titanium-aluminum (TiAl). These particles should increase the high-temperature strength of the material, improving the microstructure and thus the mechanical properties of the alloy. However, the particles must be distributed uniformly to improve grain structure and mechanical properties. On Earth, differences in density between the particles and the alloy prevent uniform distribution of the particles in the alloy. In microgravity, the inhomogeneities caused by density

differences should be reduced, and heat convection, which also affects solidification, should be negligible. This technology of microstructural control may be applied to improve high-temperature alloys needed for high-tech aircraft and spacecraft.

TiAl samples (18 mm in diameter and 25 mm in length) with and without TiB_2 will be heated to 1550 °C and solidified in microgravity. The effect of the resulting microstructure on mechanical properties (such as strength) will be studied, and the sample will be compared to ones processed under 1-g. The results will help investigators understand some of the principal phenomena that occur during this type of processing and use microstructural control for more effective Earth-processed materials. ●

Electromagnetic Containerless Processing Facility
Tiegelfreies Elektromagnetisches Prozessieren Unter Schwerelosigkeit (TEMPUS)
Payload Developer: DARA



The TEMPUS facility

TEMPUS investigators will take advantage of the facility's ability to process samples in a containerless environment, which eliminates the possibility of contamination from container walls. Scientists will study various thermodynamic and kinetic properties of some 22 samples with melting points between 600 and 2000 °C in either ultra-high vacuum or high-purity gas conditions. On Earth, high-power inputs are required for levitation, making independent temperature control impossible. In microgravity, positioning of the sample and temperature control can both be accomplished accurately and precisely because the power necessary for positioning is negligible.

For each investigation, a spherical 8- to 10- mm sample is positioned by the electromagnetic coil, melted, and then cooled. Commands are sent remotely from the ground to control facility operations, and the crew can also adjust facility operations. One class of experiments will study the samples' thermophysical properties in the regime where solidification of the molten liquid has been suppressed because of lack of heterogeneous nucleation sites on container walls. Another class of experiments will examine the kinetic properties of nucleation up to the point of maximal undercooling. (In the absence of a container, most pure molten metals and alloys freeze at temperatures substantially below those of contained liquids — the undercooling phenomenon.) Each experiment probes a fundamental property of the material in a manner that cannot be duplicated on Earth.

Effects of Nucleation by Containerless Processing in Low Gravity
Principal Investigator: Dr. R.J. Bayuzick

Experimentation in microgravity on free-floating liquids eliminates many of the stumbling blocks that occur during Earth-based studies. The experiment techniques are much less intrusive and diagnostics are greatly improved. For example, in 1-g, when the necessary forces are applied to counteract gravity, levitation techniques in the laboratory result in internal liquid flow and/or electric charge distribution on the sample surface. In drop tubes that simulate low gravity for a few seconds, the accuracy of temperature measurements does not meet experiment requirements because during free fall the specimen is moving with respect to the detectors. These experiments will describe the distribution of temperatures during the nucleation of solid from liquid. A sample of zirconium will be levitated, heated to 1950 °C, melted, and then cooled until nucleation occurs.

This levitated, molten sample is held within an Earth-bound electromagnetic heating and positioning coil system, which is similar to the one used by TEMPUS. In 1-g, the electromagnetic force must be very powerful to counteract gravity. This deforms the sample and agitates the melted alloy. In microgravity, these problems should be circumvented, allowing materials to be processed without containers that sometimes contaminate the final product.

Each experiment will consist of 100 cycles of melting, nucleation, and solidification. The nucleation temperature of the samples and the rates of growth of the solid will be recorded for comparison with Earth-based results to further the understanding of nucleation phenomena.

Alloy Undercooling Experiments

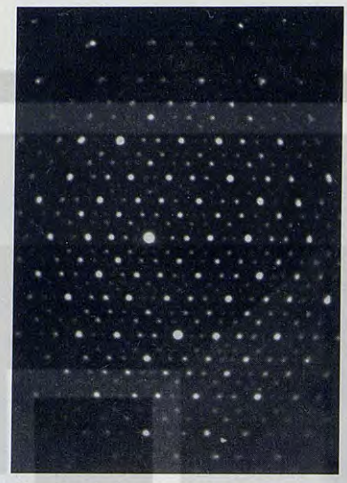
Principal Investigator:
Dr. M.C. Flemings

In this experiment, metal alloy spheres of a nickel binary system (hypoeutectic composition of nickel-25 weight percent tin and eutectic composition of nickel-32.4 weight percent tin) will be levitated, melted, and solidified. A joint experiment using pure nickel is also planned. As heat is removed and the liquid metal cools, a solid phase will nucleate and grow in the undercooled liquid. The temperature of the liquid in which the solid phase grows will determine the growth rate of the solid phase. Of particular interest in this investigation are the attainable undercoolings for each composition. A greater degree of undercooling at even lower temperatures is expected to be obtained in microgravity than is possible on Earth, and confirmation of this hypothesis will have important scientific and engineering implications.

Non-Equilibrium Solidification of Largely Undercooled Melts

Principal Investigator:
Dr. D.M. Herlach

At the extreme undercooling temperatures anticipated to be possible in this facility, phenomena in the nucleation of metastable solid phases and in rapid dendrite crystal growth are theoretically predicted but have never been experimentally verified. In particular, non-equilibrium solidification phenomena will be investigated, with special emphasis placed on the formation of metastable crystalline structures and supersaturated, grain-refined materials. Metastability



The atomic structure of a quasicrystal is revealed by X-ray diffraction, showing the five-fold symmetry not found in conventional crystals. Quasicrystals exhibit a high degree of atomic ordering but are not periodic as are ordinary crystals. Dr. Urban's experiment will examine the structure of quasicrystals processed without a container in TEMPUS.

of solids affects properties of the material, e.g., improved mechanical elasticity and strength, or in the case of magnetic materials, improved magnetic behavior. For this experiment, samples of iron-nickel, nickel-carbon, and nickel-silicon will be solidified, and several different time profiles will be obtained for each sample. The samples will be analyzed postflight along with temperture, pressure, and acceleration data.

Structure and Solidification of Largely Undercooled Melts of Quasicrystal-Forming Alloys

Principal Investigator: Dr. K. Urban

The quasicrystalline state in metallic alloys was discovered in 1984 as the third state of solid matter, in addition to the normal crystalline and glassy states. Quasicrystals exhibit excellent structural order based on atom arrangements that do not permit long-range periodicity. This feature provides quasicrystalline materials with a high degree of hardness and novel electrical and physical properties. In TEMPUS, metallic alloys can be cooled well below their melting temperature without solidification. The common explanation for this undercooling behavior is that the structure of these melts is based on atom arrangements with 20 triangular sides, an icosahedral shape. Since these are also considered fundamental to the structure of solid quasicrystals, a particular undercooling behavior is predicted for quasicrystal-forming alloys. Therefore, this experiment contributes not only to the understanding of why and how these new solids form but also to our knowledge about the structure of molten alloys. Samples of aluminum-copper-cobalt and aluminum-copper-iron will be melted and solidified. Approximately 12 different temperature profiles will be obtained for each sample. The samples and temperature, pressure, and acceleration data will be analyzed postflight.

Thermodynamics and Glass Formation in Undercooled Liquid Alloys

Principal Investigator:
Dr. H.J. Fecht

Glass can form in zirconium-based alloys by rapid cooling of the liquid or by "melting" of the crystal. To understand this phenomenon, eutectic alloys (alloys that are easily melted because their melting points are lower than that of any other alloy or mixture composed of the same ingredients) will be melted and cooled below their melting points. A new method has been developed and implemented in TEMPUS to determine the liquid's specific heat and solidification characteristics when it is undercooled. Three zirconium-based samples will be heated to 1200 K. After the experiment, investigators will use thermal, visual, and acceleration data to understand the fundamentals of undercooling and glass formation, information necessary for designing glasses for technological applications.

Metallic Glass Research in Space: Thermophysical Properties of Metallic Glasses and Undercooled Alloys

Principal Investigator:
Dr. W.L. Johnson

Containerless processing allows unique studies of the thermophysical properties of metallic glasses and undercooled alloys. Specific heat (the amount of heat required to increase the temperature of 1 gram of material by 1 °C), maximum undercooling temperature, and other thermophysical properties — for which no data presently exist in the extremely undercooled regime — will be measured. Such data are necessary to test various theories of crystallization and glass formation and will be a major contribution toward the understanding of the fundamental behavior of metastable materials. Metastable materials such as metallic glasses have found applications in many technological areas because of their superior mechanical and physical properties; some present areas of application include high-powered laser choke switches, transformer cores, brazing alloys, wear-resistant coatings, and reinforcing fibers in metal matrices. In the very near future, these injection-molded, bulk metallic glasses should influence the state of materials science and engineering.

Viscosity and Surface Tension of Undercooled Melts

Principal Investigator: Dr. I. Egry

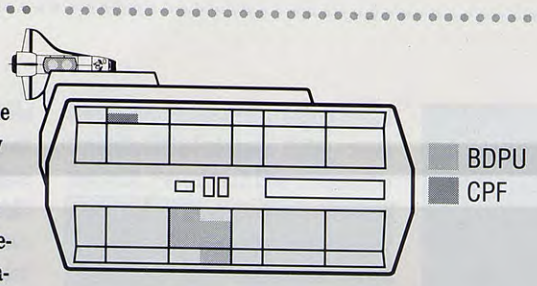
The strong electromagnetic forces needed to overcome Earth's gravity limit the study of the viscosity and measurement of the surface tension of liquid metals in the laboratory. The microgravity environment, however, will allow the TEMPUS facility to use only minimal forces to position droplets of melted metals, such as nickel and gold, to be suspended and acted upon by minimal gravitational forces. The samples will be levitated and melted, the heating

power will be switched off, and the liquid sample will be cooled below its melting point. At predefined temperatures, oscillations will be induced in the sample, and the frequency and damping of the oscillations will be measured. From these data, surface tension and viscosity can be derived. During the mission, the experiment will be repeated as many times as possible. While earlier research has indicated the feasibility of high-precision measurements for surface tension and viscosity, such measurements have never before been possible. As a result of this experiment, our understanding of microscopic interactions within undercooled metal samples could be greatly expanded.

Measurement of the Viscosity and Surface Tension of Undercooled Melts under Microgravity Conditions and Supporting MHD Calculations

Principal Investigator: Dr. J. Szekely

The unique attributes of microgravity offer the chance to determine the viscosity and surface tension of undercooled metallic melts. Knowledge of the viscosity of melts below their freezing temperatures will make an important contribution to the hydrodynamic description of fluids in this metastable state. The growing field of electromagnetic processing of materials, especially the area of electromagnetic shaping of electrically conducting fluids, will benefit from this research. An electromagnetically positioned molten metal droplet will be squeezed by pulsing the heating coils of the TEMPUS system. Once the squeezing force is discontinued, the sample will relax through a series of damped oscillations. The surface tension may be deduced from the frequency of the oscillations, and the viscosity can be determined from the rate at which these oscillations are damped. ●

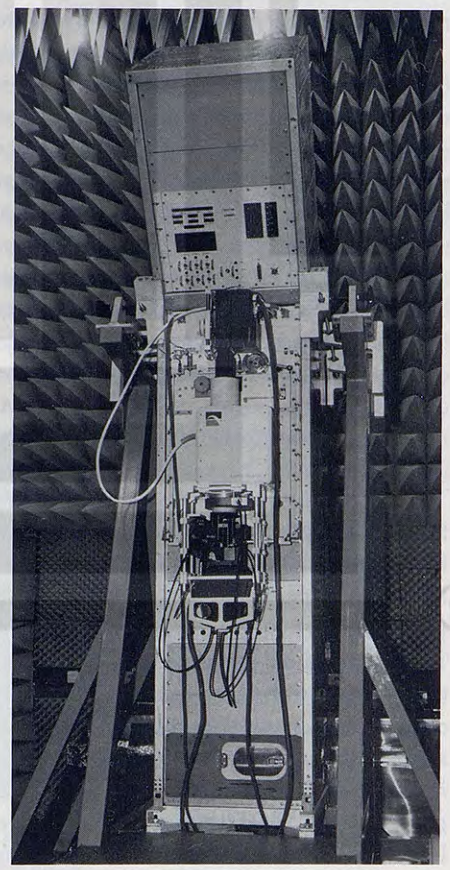


Bubble, Drop, and Particle Unit (BDPU)

Payload Developer: ESA

Advances in materials processing have the potential to produce new high-strength metals and temperature-resistant glasses and ceramics for building everything from better electric power plants to future spacecraft. However, to advance materials research in microgravity, scientists need a better understanding of fluid processes that play a role in the production of most materials. Investigations in this facility will help characterize interfacial processes involving either bubbles, drops, or liquid layers. On Earth, gravity-induced convection, buoyancy, sedimentation, and hydrostatic pressure often mask these interfacial effects. In contrast, the space-based BDPU investigations will be able to quantitatively measure more subtle fluid processes.

Commands will be sent from the ground to inject bubbles or drops into liquid-filled test cells and then to subject the cells to predetermined changes in temperature. Cameras and sensors will observe and record temperature, density, and position of the bubbles or drops. The various test cells will be used to study how bubbles and drops react in liquids with varying temperatures and concentrations, how they affect the process of solidification, how convection affects liquid layers under different temperature conditions, and how evaporation and condensation affect bubble creation and growth.



The BDPU facility

Bubble Migration, Coalescence, and Interaction with Melting and Solidification Fronts

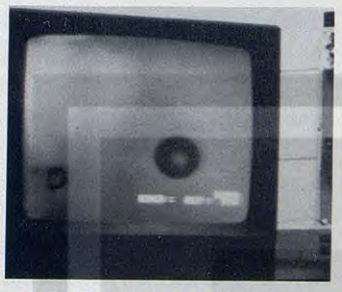
Principal Investigator: Dr. R. Monti

As molten alloys, crystals, and glasses begin to solidify, bubbles may form and small particles (inclusions) occasionally coalesce, causing imperfections within the final product. This investigation will provide new insight into how best to prevent these flaws from occurring in metals and alloys as they are being produced in the microgravity environment. The test sample will be a solid matrix of tetracosane, a material that melts at a low temperature. The matrix will include pre-formed bubbles of different sizes. As the tetracosane is heated higher than its melting point (55 °C) and the melting front reaches the bubbles, the bubbles will be released and migrate toward the hot side. The locations and dimensions of the bubbles released by the melting front and other characteristics of the migration will be studied and documented. When the solid is completely melted, the walls will be cooled, and a new solidification phase is started to study the interaction of the migrating bubbles with the solidification front. In the second part of the experiment, drops of different diameters will be injected into a liquid matrix to study drop behavior.

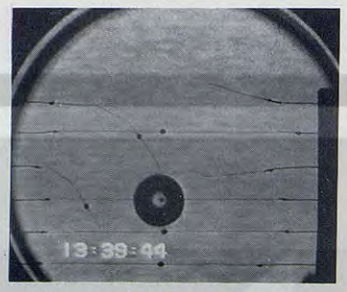
Thermocapillary Migration and Interactions of Bubbles and Drops

Principal Investigator: Dr. R.S. Subramanian

Bubbles and drops are encountered in various materials processes, such as solidification and preparation of composite materials. Also, for long-duration space voyages, recycling of waste material will be essential, and separation processes used for this purpose may involve bubbles and drops. Therefore, it is important to understand the motion of bubbles and drops and to learn to manipulate them under low-gravity conditions where buoyancy is negligible.



In Dr. Subramanian's laboratory, video is used to record drops of ethylsalicylate as they migrate under the action of a temperature gradient in diethylene glycol. Experiments similar to these will be conducted during the IML-2 mission.



This vapor bubble was generated during the reduced-gravity portion of a KC-135 aircraft's parabolic flight. The bubble was initiated by a 0.5-second pulse from a spot heater, the dark circle in the center of the bubble. In 1-g, this phenomenon cannot be studied because of buoyancy.

In this experiment, the movement and shape of gas bubbles and liquid drops under the action of a temperature gradient will be studied. The temperature gradient will cause a variation of the interfacial tension at the interface of the bubble or drop, which should propel it in the direction of warmer liquid. The speeds as well as the shapes of isolated and interacting bubbles and drops will be obtained. Six series of runs, each lasting about 4 hours, will be conducted. In each series, a temperature gradient from 0.1 to 1.0 K/mm will first be established in the test fluid. Approximately six bubbles (or drops) will be injected in sequence, and their motion will be monitored on the ground via video. Then, the bubbles or drops will be extracted in preparation for the next series of runs. Results from the experiments will be compared with predictions from theoretical models.

Bubble Behavior Under Low Gravity

Principal Investigator: Dr. A. Viviani

This experiment investigates the motion of bubbles immersed in a liquid with a non-uniform temperature distribution. The motion of the particles is driven by variations in the surface tension, which are induced by temperature differences along the interface between the liquid matrix and the injected particles. This study has applications for many aspects of materials science and can only be studied in a microgravity environment because Earth's gravitational field acts on density differences between air and liquid, making buoyancy forces predominant. These forces mask the motion of bubbles caused by interfacial tension.

Bubbles of inert gas will be injected into an aqueous solution of n-heptanol under a thermal gradient. Investigators will determine the non-uniform velocity of the injected bubbles and attempt to stop them in certain desired positions. The experiment will be repeated with several bubbles of different dimensions (2 to 10 mm in diameter) and under different thermal gradients. Images of the bubble migration will be recorded and downlinked to investigators on the ground.

Interfacial Phenomena in a Multilayered Fluid System

Principal Investigator: Dr. J.N. Koster

This experiment will study thermocapillary motion (convective flow caused by temperature changes on a liquid's surface) in a multilayered immiscible fluid system — a very poorly understood fluid behavior. Immiscible fluids (fluids that do not mix) are used to establish two liquid-liquid interfaces in this three-layer system composed of fluorinert™), silicone oil, and fluorinert™. Motions generated at one interface compete with motions generated by the second fluid interface. The objective of this investigation is to observe the interdependent interactions between the individual layers due to temperature gradients. Temperature-driven flow throughout all three fluid layers will be measured using tracers inside the liquid. Corresponding temperature measurements will also be made. These data will be compared with computer model results and will subsequently help validate the models, yielding a better understanding of the underlying physics involved in these processes.

Studying interfacial forces in low gravity will provide new and fundamental insight into a complex field of fluid physics that cannot be studied on the ground. Results will eventually lead to criteria that improve crystal growth in space. In addition, the knowledge and ground-based research involved in this effort will help scientists better understand liquid encapsulated crystal growth and other immiscible fluid flows related to environmental water pollution caused by oil spills. The results will complement Dr. Legros' investigation adding to scientists' knowledge of thermal interfacial flows.

A special test container was developed for this experiment and Dr. Legros'. Until the experiment is begun on orbit, the three fluid layers are separated by two metal curtains in the container.

Thermocapillary Instability in a Three-Layer System

Principal Investigator: Dr. J.C. Legros

This experiment, along with Dr. Koster's investigation, will provide the first information on the departure from the rest state of a multi-layer system under the influence of surface-tension forces. It will allow scientists to describe quantitatively the convective pattern arising in three layers of immiscible liquids (fluorinert™, silicone oil, and fluorinert™). Heating sources above and below the liquid layers are used to create a temperature gradient that is perpendicular to the two liquid-liquid interfaces established between the fluids. When set temperatures are reached and stabilized, video and infrared images of the convective motion are downlinked to investigators on the ground. This phase is repeated several times with different thermal gradients. The objective of this experiment is to understand the loss of stability of a system with two adjacent free interfaces subjected to surface-tension forces. The experiment will be conducted in a test container identical to that used in Dr. Koster's experiment. Together with Dr. Koster's experiment results, this investigation will lead to a better understanding of the technique of floating-zone encapsulation and its effect on the convective stability of the zones.

Nucleation, Bubble Growth, Interfacial Micro-Layer, Evaporation and Condensation Kinetics

Principal Investigator: Dr. J. Straub

This experiment investigates the evaporation and condensation kinetics at the interface of a single vapor bubble in a homogeneous supersaturated liquid under well-defined conditions. The isothermal liquid, a refrigerant, is brought to a supersaturated state by reducing the pressure. A vapor bubble is generated by a short heating pulse of a spot heater in the liquid. The process is studied at several temperatures between ambient and 100 °C. In Earth's gravity, vapor bubbles disappear very rapidly from the field of view. In microgravity, however, a vapor bubble will remain where it nucleates, will grow in size, and can be observed. The most important

aspect of this investigation is to understand the evaporation and condensation at liquid interfaces. This is an integral part of environmental evaporation in seas, lakes, and rivers; in many technical applications, like boiling in heat exchangers; in many energy conversion system processes; and in the chemical industry.

Static and Dynamic Behavior of Liquid in Corners, Edges, and Containers

Principal Investigator:
Dr. D. Langbein

This experiment will confirm the existence and the stability limits of particular liquid surfaces in cylindrical containers. It will prove a key principle used in many microgravity experiments and in designing surface-tension tanks, a tank that provides fuel at the outlet via capillary effects alone. It does not need a piston but transports fuel to the outlet by edges, decreasing dihedral angles, conical guides, etc. This experiment will give insight into wetting phenomena caused only by capillary forces. A liquid (Cargille 50350, which has the same refractive index as quartz) is injected into the quartz test cell, containing different transparent polygonal cylinders of different dihedral shapes. The cell is maintained between 30 and 80 °C. The surface shapes produced as the temperature and liquid volumes are changed will be observed using background and cross-section illumination. The experiment goal is to make precise measurements of contact angles between non-transparent metallic melts and crucibles. ●

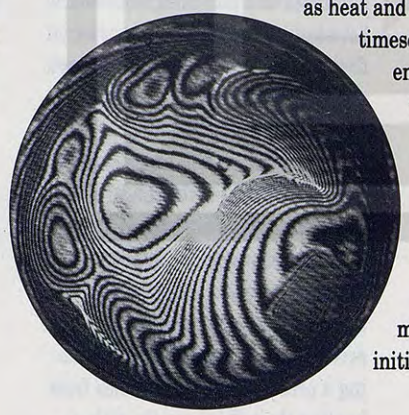
Critical Point Facility (CPF)
Payload Developer: ESA

During IML-1, Payload Specialist Dr. Ulf Merbold monitors a CPF experiment. Scientists witnessed critical point phenomena never seen before on Earth during this first flight. The IML-2 experiments will build on these results.

At what is called the critical point, temperature and pressure compel two states of matter (phases, such as gas and liquid) to become identical and form one phase. Any pure fluid undergoes such changes at its critical point. On Earth, fluids cannot be sustained precisely at their critical point long enough to be observed and analyzed. Indeed, a fluid's compressibility is infinite at its critical point. As a result, the fluid is immediately compressed under its own weight and separates into a denser phase and a lighter phase — destroying the critical state. In space, however, microgravity reduces the weight compression effects that disturb a fluid undergoing this critical transition, making it possible to study unfamiliar thermodynamic properties of diverse fluids at their critical points.

The CPF thermostats, which house one or two test cells that hold sample fluids, maintain a sample at a precise, stable, and homogeneous temperature (better than 0.0001 K). The facility also quenches samples, cooling them quickly, and provides electrical stimulation, stirring, pressure measurement, and local heating within the fluid sample. The samples are monitored continuously by direct observations via downlinked video images; scattering of laser light at angles ranging from very small ones to 90 degrees; interferometry, which shows the local fluid density changes in various parts of the cell; and turbidity, the transparency of the fluid. Real-time video is available to investigators on the ground along with digitized video snapshots, at 6-second intervals, of the phenomena in progress. Although CPF experiments run automatically, investigators working on the ground can send remote commands to modify their experiments in real time, as was done more than 1,000 times during the instrument's first flight on IML-1.

The applications of this research extend beyond the CPF sample fluids to all pure fluids and to other physical systems that undergo critical phase changes. The research can be applied to supercritical fluids, which are simultaneously dense and compressible, used for more and more technological applications. The research is also expected to provide a better understanding of the behavior of fluids in rocket and spacecraft thruster reservoirs, since these fluids are typically supercritical and could reach the critical point during thruster operations. Besides increasing knowledge of fluid behavior, such as heat and mass transport and equilibration timescales, this research will improve scientists' understanding of the formation of interfaces between two distinct phases in microgravity. This research is related to practical applications of fluids, such as processes inside heat exchangers, cleaning methods involving fluids at high pressure, and quenching of metallic alloys where separation is initiated in the liquid phase.



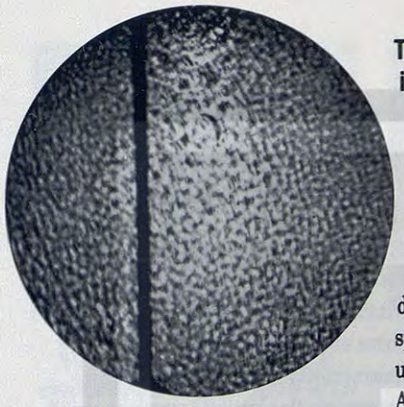
This interferometric image provided scientists with data about fluid phase transitions at the critical point.

The Piston Effect

Principal Investigator:
Dr. D. Beysens

Very compressible supercritical fluids, such as sulphur-hexafluoride (SF_6) near its critical point (46 °C), can exhibit a very fast transport of heat through convective flows that are not caused by gravity. A hot boundary layer can expand and heat the bulk of the fluid like a real piston. Thermalization is expected to be homogeneous within a time intermediate between typical acoustic times (μs) and heat diffusion times (hours or days). Recent numerical simulations and experiments on sounding rockets (TEXUS), the Spacelab IML-1 mission, and the MIR space station have demonstrated the existence of the thermocompressible transport of heat, but scientists still know very little about the characteristics of this effect.

During IML-2, a number of experiments will be performed to determine the temperature, density, and pressure evolution using a temperature sensor or a laser beam. The coupling of the phenomenon with a



This visual image shows vapor droplets 2 hours after the onset of phase separation. The domains are not uniform because of the laser beam that was present at the beginning of the experiment. Its influence is still not understood and will be investigated during Dr. Beysens' experiment.

weak, controlled acceleration caused by a Shuttle maneuver and the influence of capillary flows driven by the phase separation process will also be studied. For this experiment, two fluid samples in the same thermostat will be studied simultaneously over a 43-hour period.

Thermal Equilibration in a One-Component Fluid

Principal Investigator: Dr. R.A. Ferrell

This experiment is designed to study the critical point properties of a single fluid. The critical point is the point in the temperature-density diagram for the fluid that is specified by definite and precise values for the temperature and density. As the temperature of the fluid is lowered below the critical point, the fluid will undergo a phase transition and transform into two co-existing phases, liquid and gas. Above the critical temperature, the two phases merge, and there is no distinction between the liquid and the gas. The experiment will be conducted with the fluid sulphur-hexafluoride, which has molecules that form a positive sulfur ion surrounded by a cage of six negative fluoride ions. These small spherical structures exert a repulsive force on one another at short range and an attractive force at greater separations. It is this competition between interactions that leads to the phase transition that occurs at the critical point. Very close to the critical point, two mechanisms for energy transfer — heat diffusion and pressure (imposed work) — become quite different with varying time scales. Heat diffusion occurs

This visual image of SF_6 shows two phases at $T = T_c - 3$ mK. The most notable feature is the variable and small surface tension around the large central vapor bubble. This vanishing surface tension is a trait of fluids at their critical point. Similar phenomena will be investigated during Dr. Ferrell's experiment. The bar at the right bottom is the stirrer. (No stirrer will be used on IML-2.)

very slowly near the critical point, while pressure changes within the fluid cause changes much more rapidly. The goal of this experiment is to study quantitatively the competition and interaction of these two energy transport mechanisms. The data obtained will be useful in designing subsequent critical point fluid experiments to minimize the role of heat diffusion and the inconveniently long times that diffusion entails.

The experiment has two parts, each to be performed in a separate thermostat. Both thermostats will hold two fluid cells with a layer of fluid (1 or 2 mm thick) confined between transparent windows at the proper critical density. One part studies heat diffusion, and another studies how pressure transports energy. Diffusion will be studied by heating one side of the thermostat to establish a steady heat flow across the cell and tracking the time evolution of temperature and density changes. The other energy transport process will be studied by introducing a pressure step that comes from heating the cell internally with a pulse of current passing through a wire in the cell. When the wire is charged to a static potential of 500 volts, the pull of SF_6 molecules into the electric field around the wire will cause a local density change that can be observed by interferometry. The response of the fluid in both thermostats will be monitored using the CPF's optical systems.

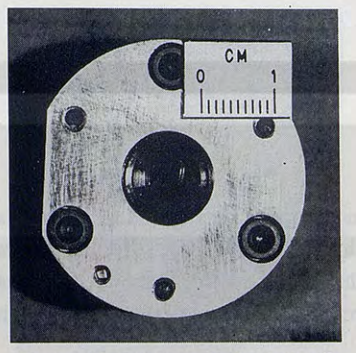
Density Equilibration Time Scale

Principal Investigator: Dr. H. Klein

Thermal diffusion was once thought to cause thermal equilibrium of fluids near the critical point. The results of recent space experiments have led to a revision of this point of view. To describe mathematically the equilibration process in fluids near the critical point, scientists are debating the need for complete solution to the coupled equations of heat and mass transport, which is an extremely difficult undertaking. Efforts are being made to identify mechanisms (e.g., mass diffusion across gas/liquid interfaces) that are assumed to play a major role in respective equilibration processes. In general, knowledge of mass transport associated with gas/liquid phase

transitions is rather poor. The objective of this investigation is to learn more about mass transport, particularly near the critical point. Investigators will observe the development of density differences between gas and liquid sample sections, as well as dissolution of density irregularities. The latter survive as the two-phase state evolves into a one-phase state at equilibrium. Related equilibrium time scales are expected to be quite different from the ones estimated on the basis of thermal diffusivity. This investigation is intended to be a contribution to basic research and, in addition, aims at reliable data on equilibration time scales to be used in the design of critical point experiments.

Sulfur-hexafluoride was selected as the sample system because it serves as a model system in critical point investigations, is chemically inert, and has moderate critical conditions. The critical density of the sample permits a wide range of gas/liquid states (including the critical point) to be studied just by changing the temperature. At the critical point, the response functions and transport processes are expected to exhibit a singular behavior. This implies that the fluid is highly susceptible to the influences of gravity (such as sedimentation and convection), which interfere with the mass transport being studied. Therefore, this experiment must be conducted under reduced gravity conditions.



The small center area is the test cell where CPF experiments take place.

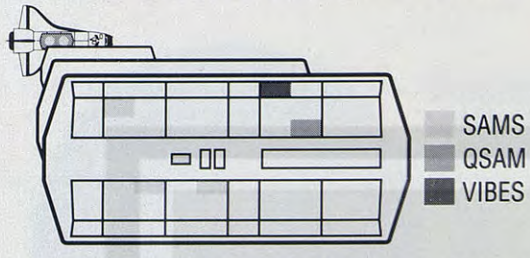
Heat Transport and Density Fluctuations in a Critical Fluid

Principal Investigator:
Dr. A.C. Michels

In a fluid, there are three fundamental mechanisms for transport of heat. Close to the critical point, where the system becomes very compressible, these heat transport mechanisms operate on vastly differing time scales. The first mechanism is propagation of sound. The second is thermal diffusion, which becomes ever slower as the critical point is approached. The third is adiabatic compression heating, heating with negligible gain or loss of heat. Since the fluid becomes increasing compressible as it nears the critical point, adiabatic compression becomes dominant in the near-critical state. On Earth, heat transport investigations are flawed by gravity-driven convection; this space-based investigation, however, will allow scientists to study the relevant importance of the last two mechanisms in detail in a convection-free environment. An understanding of the nature of microscopic fluctuations in the fluid is critical for interpreting the results. Fluctuations in the fluid sulfur-hexafluoride will be recorded by laser light-scattering. ●

The CPF imagery is sent directly to the ground control center at MSFC, where scientists can analyze it. If they want to change experiment parameters, such as temperature, investigators can command the CPF directly from their consoles in the control center.

MICROGRAVITY ENVIRONMENT AND COUNTERMEASURES

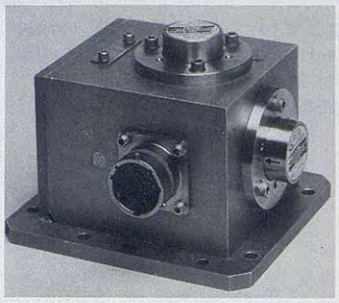


The IML-2 mission has been designed especially to provide the highest quality microgravity environment achievable aboard the Space Shuttle. Many of the IML-2 experiments require a very smooth ride through space so that their delicate operations are not disturbed. The best way to maintain a stable drift is to keep the tail of the Shuttle pointed toward Earth. In this orientation, called a gravity gradient attitude, the vehicle's position is maintained primarily by natural forces, reducing the number of orbiter thruster firings that disturb acceleration-sensitive experiments.

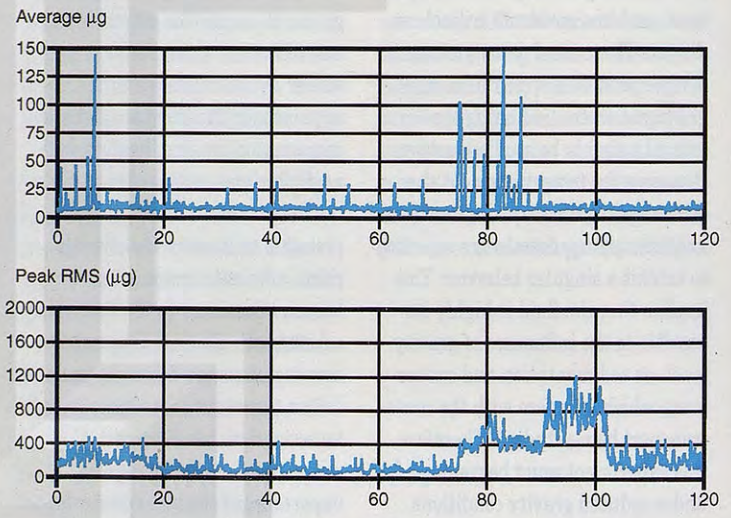
Even in a gravity gradient attitude, accelerations caused by crew movements, equipment operations, and occasional thruster firings can disrupt the quiescent low-gravity environment and may affect microgravity science experiments. Accelerations at particular frequencies may interrupt one type of experiment but have no effect on others. These accelerations are measured at fractions of Earth's gravity; for instance, 10^{-5} g is equal to 1/100,000 of the gravity on Earth. To measure accelerations and their effects, two systems, which record magnitudes at different frequency ranges, will be flown on IML-2. They provide data to investigators who then can identify accelerations that may have influenced their experiments. In addition, experiments will be performed to test a damping system that may counteract the effect of some accelerations.

Space Acceleration Measurement System (SAMS)
Payload Developer: NASA
Principal Investigator: Mr. C. Baugher

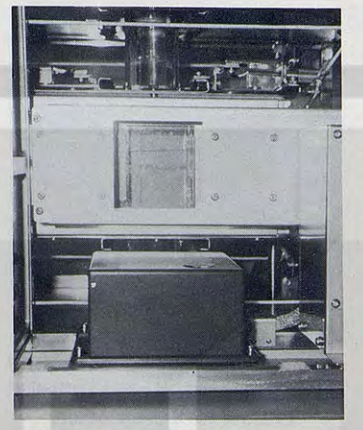
This system, developed at the NASA Lewis Research Center, obtains high-frequency acceleration measurements in support of microgravity experiments. Three remote triaxial sensors measure accelerations, which are recorded by a microprocessor-driven data acquisition system located in the Spacelab center aisle. The sensor located near the BDPU in Rack 8 measures frequencies of approximately 10 Hertz, the sensor located near the CPF in Rack 9 measures frequencies of approximately 5 Hertz, and the sensor located near the TEMPUS in Rack 10 measures frequencies of approximately 100 Hertz. These materials and fluid science experiments are particularly sensitive to frequency ranges that SAMS will record. SAMS operates continuously for the length of the mission. ●



One of three SAMS triaxial sensor heads



These charts are examples of the data provided to investigators after flight. The examples show 2 hours of Spacelab acceleration data. The lower plot line indicates the overall level of acceleration disturbances, and the upper plot line reveals the results obtained when the same data are averaged over 10-second intervals. The averaged data show spikes about 75 minutes into the plot. They are a result of vehicle thruster firings to change the orbiter attitude.

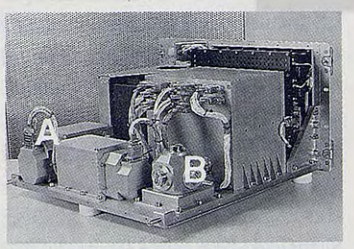


A window in the VIBES unit allows video observation of experiments conducted with and without damping.

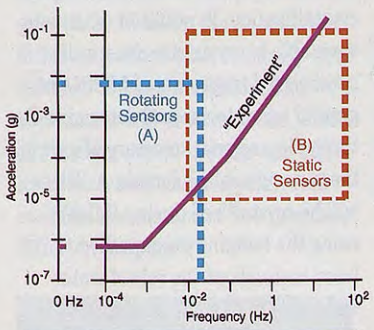
Vibration Isolation Box Experiment System (VIBES)
Payload Developer: NASDA

VIBES investigates the effect of microgravity jitter, caused by crew and experiment equipment operations inside Spacelab. These jitters or accelerations affect experiments that are designed to process samples in a low-gravity environment. Two experiment containers are installed separately in the vibration isolation box. A special visco-elastic material made of silicone polymer is used to damp accelerations. Two triaxial acceleration sensors are mounted in the inner and outer compartments and provide comparative microgravity jitter levels. The experiments will be performed with and without the damping lock mechanism in place to determine the effectiveness of the material. Portholes are available for video camera observations of the experiments inside VIBES.

Quasi-Steady Acceleration Measurement (QSAM)
Payload Developer: DLR
Principal Investigator: Dr. H. Hamacher



The QSAM acceleration measurement device



This chart shows the measurement ranges of QSAM. The "Experiment" line represents the level of acceleration a typical Spacelab fluid physics experiment will tolerate.

The QSAM system is primarily designed to detect steady, very low-frequency, residual accelerations between 0 and 0.02 Hertz. In this range, the acceleration level is typically 10^{-6} g or even lower, and these low-frequency accelerations affect various physical processes more than higher frequency accelerations. Unlike other measurement systems, QSAM suppresses the sensors' bias and noise to assess this acceleration range with a minimum of on-orbit maintenance. To achieve this, the measurement signal can be modulated by rotating a sensor's sensitive axis. The system employs four rotating sensors to allow three-dimensional acceleration detection. An additional package with stationary sensors has an upper bandwidth of 50 Hertz. The QSAM system is located in one rack inside the laboratory, but data can be modeled to calculate the low-frequency accelerations at other locations inside the orbiter. These measurements of quasi-steady accelerations will help establish a database characterizing the microgravity environment aboard Spacelab. QSAM complements SAMS, providing detection of the entire range of accelerations that may affect experiments. ●

Influence of G-Jitter on Natural Convection and Diffusive Transport
Principal Investigator: Dr. H. Azuma

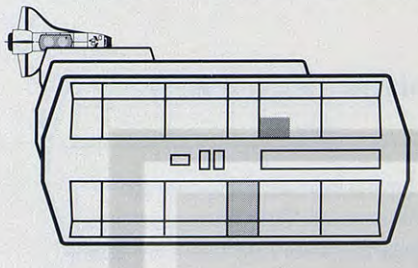
Fluctuation of microgravity levels at various frequencies, known as g-jitter, affects experiments that need a constant microgravity environment. This experiment measures the effects g-jitter and the residual gravity of the Shuttle have on flow and diffusion in a liquid with a thermal gradient and studies VIBES' ability to isolate experiments from this jitter.

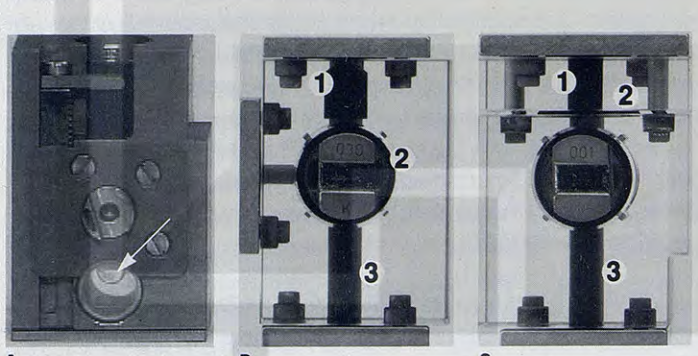
A rectangular container is filled with diluted salt solution that includes indicator dye and is installed inside VIBES. To create a thermal gradient in the water, one side of the container will be heated. The flow caused by residual gravity and g-jitter can be tracked by observing colored dye. The colorful flow patterns can be viewed by video camera to allow investigators to study convection as well as material transport by diffusion. The experiment is performed both with and without the damping system during periods of intense crew activity, which may create higher g-jitter.

Study on Thermally Driven Flow under Microgravity
Principal Investigator: Dr. M. Furukawa

As spacecraft become larger and more complex, they generate more heat and require improved thermal management systems. This experiment studies the basis for a more efficient thermal management system that can transport liquid that separates from co-existing vapor in microgravity. The results will also contribute to the design of fuel cells, power plants, and environmental and life support systems that require thermal management of liquids.

The objective of this experiment is to test the VIBES accumulator, comparing its fluid transporting characteristics with and without the g-jitter damping mechanism. Inside, the accumulator consists of two vessels, and water in the vessels is heated and cooled by thermoelectric devices. The liquid will move from the hotter vessel to the cooler one as a result of vapor pressure differences generated between the vessels. On Earth, the system works well because spontaneous gas/liquid separation occurs at the vertical orientation. In microgravity, however, surface tension and capillary forces, which dominate such buoyancy, will play a significant role in separating the fluid flow. Behavior of the liquid flow and two-dimensional vapor/liquid distributions will be recorded on video and analyzed with the VIBES function. ●





A B C

The APCF is the first facility to make it possible to grow protein crystals by three techniques. (A) Hanging drop chamber. The arrow points to a drop hanging in the chamber. (B) Free interface diffusion chamber. The upper cylinder (1) contains the protein solution; the center section (2) holds the buffer; and the lower cylinder (3) is the reservoir of precipitating agent. (C) Dialysis chamber. The protein solution is located in the upper cylinder (1) and is separated by a membrane (2) from the precipitating agent, located in the lower cylinder (3).

Advanced Protein Crystallization Facility (APCF)

Payload Developer: ESA

Conditions on Earth limit the size and quality of protein crystals, but the microgravity environment of space is expected to allow the manufacture of larger, more highly ordered crystals. The APCF is the first facility ever designed to use three methods of protein crystal growth. One will employ liquid-liquid diffusion, or free interface diffusion, in which a protein solution and a salt solution are separated by a buffer and are allowed to flow together slowly once the Shuttle is in orbit. Another will use the dialysis method, with protein and salt solutions separated by a membrane. The third process is vapor diffusion, or the hanging drop method, where crystals form inside a drop of protein solution as solvent from the drop diffuses to a reservoir. For all three methods, crystallization will occur at constant temperatures of 4 °C and 20 °C.

Upon reaching orbit, the crew activates the unit, monitors the facility as it operates, and deactivates the equipment when experiments end. Video images will be made of crystals as they form. After the mission, the approximately 5,000 video images will allow investigators to study the history of crystal development in microgravity. Scientists are interested particularly in why and how crystals nucleate to begin crystal formation. The crystals returned from space will be analyzed to determine their internal arrangement of molecules. As X-rays diffract off the atoms of the crystals, a computer will map each atom's position. With these protein maps made using larger, more highly ordered crystals, scientists may be able to expand our understanding of biological processes on the molecular level, which could lead to applications in medicine and agriculture.

Often the proteins that are selected for crystallization and their growth methods are not defined until just before a Shuttle flight. Some of the following experiment descriptions contain information about candidate proteins for IML-2.

Crystallization of Medically and Biologically Related Proteins

Principal Investigator: Dr. D. Blow

The objective of this experiment is to grow high-quality protein crystals at 4 °C and 20 °C using the hanging drop method.

Protein Crystal Growth at Known Supersaturation

Principal Investigator: Dr. A. Ducruix

This experiment will grow several types of protein crystals in microgravity using the hanging drop and dialysis methods at a temperature of 20 °C. One objective is to grow better crystals of the Photochemical Reaction Center found in Rhodobacter spheroids. Crystals of collagenase, which belong to the family of proteases responsible for the cleavage of collagen, will be isolated from *Hypoderma lineatum* and crystallized. The influence of microgravity on the growth rate of lysozyme crystals in the presence of p-toluene sulfonate will also be studied because this protein has a high growth rate and is thus a good model for crystal growth rate.

Crystallization of Visual Pigment Rhodopsin

Principal Investigator: Dr. W.J. de Grip

Visual pigments like rhodopsin are the primary photoreceptor proteins for a variety of light-regulated processes like vision, circadian entrainment, and photoperiodic reproductivity. To unravel the molecular mechanisms responsible for these processes, high-quality crystals suitable for analysis by X-ray diffraction are needed. The crystals will be grown at 20 °C in either darkness or deep red light using the hanging drop method.

Crystallization of Ribosomal 5S RNA

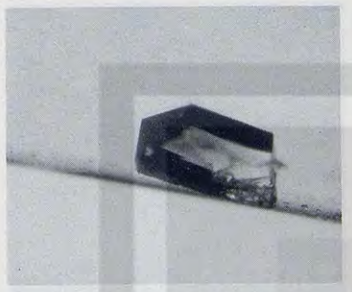
Principal Investigator: Dr. V.A. Erdmann

Ribonucleic acid (RNA) molecules have diverse biological roles, such as carrying genetic information (mRNAs) or amino acids (tRNAs) to the ribosomes during protein synthesis and participating as constituents (rRNAs) of the ribosomes as they carry out biological functions. RNA molecules (ribozymes) may even exhibit enzymatic activities. To fully understand the many biological functions of RNA molecules, scientists must determine the atomic structure of RNA. Because of the large molecular weights of RNA molecules, it has been extremely difficult to crystallize them on Earth. The objective of this investigation is to crystallize the ribosomal 5S RNA using the dialysis method. In preparation for IML-2, 5S RNA has been crystallized on the ground using numerous different molecules, but higher quality crystals must be obtained before its structure can be determined by X-ray diffraction. These ground-based studies showed that 5S RNA molecules from thermophilic eubacterium (*Thermus flavus*) was best suited for crystallization and represents a good model system for the studies of microgravity on crystallization. In addition, scientists were able to crystallize chemically synthesized fragments of 5S RNA in ground laboratories and determine the three-dimensional structure of part of the molecule called domain A. These will be crystallized during IML-2 using the hanging drop method to learn more about the role of water molecules in RNA structures.

Crystallization of tRNA

Principal Investigator: Dr. R. Giegé

The objective of this experiment is to grow high-quality crystals of concanavalin A, aminoacyl tRNA synthetase, and tRNA using the hanging drop and liquid-liquid diffusion methods at temperatures of 4 °C and 20 °C.



Crystals, such as this one of ribosomal 5S RNA, will be grown in Dr. Erdmann's experiment.

Crystallization of Lysozyme

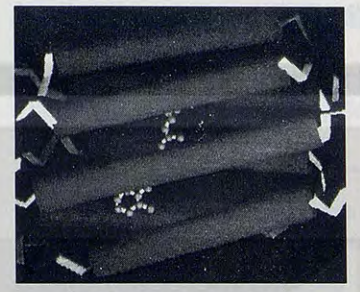
Principal Investigator:
Dr. J. Helliwell

The objective of this experiment is to grow high-quality crystals of lysozyme and concanavalin A at 4 °C using the liquid-liquid diffusion method.

Microgravity Effects on Macromolecule and Virus Crystallization

Principal Investigator:
Dr. A. McPherson

This experiment will grow high-quality crystals of several biologically important micromolecules, including at least one virus. Candidate proteins for flight include canavalin, satellite tobacco mosaic virus, malic enzyme, phospholipase A2, EF Tu Antibiotic complex, and porin. The crystals will grow at 20 °C using the liquid-liquid diffusion method with relatively large volumes of sample solution. The experiment will determine the effects of microgravity on the size and quality of macromolecular crystals and evaluate the method of free interface diffusion in space.

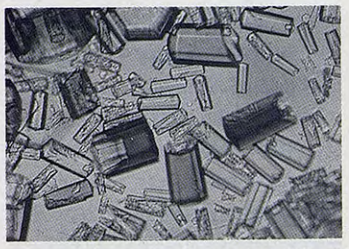


In this computer model of bacteriorhodopsin, developed from two-dimensional native crystals, seven cylindrical alpha helices form a "cage" around the internal structure. During IML-2, scientists will seek to refine details of the protein's photo-voltaic control center located inside the cage.

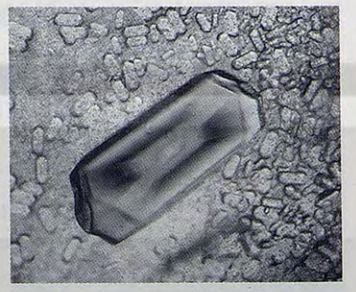
Crystal Packing Interactions Between Different Crystal Forms of Macromolecules Grown on Earth and in Microgravity

Principal Investigator: Dr. L. Sjolin

This experiment will grow high-quality crystals of several types of proteins in microgravity at 20 °C using the liquid diffusion and hanging drop methods. Complexes of HIV protease and inhibitors are of interest because understanding them may help researchers find drugs for the treatment of AIDS. Allosteric enzymes like threonine deamidase play a pivotal role in regulation of the metabolism, and studies of their interactions can yield insight into a fundamental attribute of all living organisms: maintenance of homeostasis. Another protein of interest, azurin, belongs to a class of small cupredoxins and functions with cytochrome as an electron transporter in bacterial systems.



The hexagonal prismatic crystals of the protein canavalin (left) were grown during the IML-1 mission by liquid-liquid diffusion. The right image shows rhombohedral crystals grown by vapor diffusion. These crystals are some of the most nearly perfect canavalin crystals grown on Earth or in space.



This crystal of satellite tobacco mosaic virus is unusually large (~1.5 mm x 1 mm x 1 mm). It was grown in the Cryostat facility, a protein crystallization facility flown on IML-1. The crystal is virtually flawless; the edges are sharp. Under polarized light in Dr. McPherson's laboratory on Earth, the crystal yielded striking interference colors never seen before. The data gathered about the protein's structure using X-ray diffraction were substantially better than data obtained from similar crystals grown on Earth.

Crystallization of Intact Ribosomal Particles under Microgravity

Principal Investigator: Dr. A. Yonath

Of all organelles in the living cell, only the ribosome has thus far been crystallized. These are the universal supramolecular assemblies that are responsible for one of the most fundamental life processes: the translation of the genetic code to proteins. Crystals of favorable morphology must be grown to elucidate the three-dimensional structure of ribosomes at the molecular level using X-ray crystallography. Currently, most of the ribosomal crystals grown on Earth are very thin and crack upon handling, which causes severe difficulties in data collection and evaluation. Crystals grown in microgravity may have improved internal order, morphology, size, and mechanical properties. Previous space experiments have yielded crystals of attractive morphologies, but they were still not suitable for efficient data collection. Higher quality crystals are expected to grow in the APCF because the growth chambers are almost tailor made for growing this type of protein crystal. The facility may also allow scientists to control specific properties of this crystal's morphology.

Crystallization of the Small Receptor Molecules Archaebacterial Rhodopsin and Plant Calmodulin

Principal Investigator:
Dr. G. Wagner

The objective of this experiment is to grow isodiametrically large, highly ordered protein crystals of bacteriorhodopsin and calmodulin. Bacteriorhodopsin is a well-known membrane protein that converts light energy to voltages in the membrane of photoenergetic microorganisms that are chemically and genetically distinct from bacteria and higher living organisms. Resolution of the three-dimensional structure of this protein will help scientists understand the mechanisms used to convert light to energy, which was necessary for early life on Earth. Bacteriorhodopsin crystals grown during the IML-1 mission were as good as the best crystals ever grown in the ground laboratory during innumerable experiments spanning more than a decade. To attempt to grow even better crystals during the IML-2 mission, protein and detergent concentrations will be varied and tested under microgravity conditions. The crystals will be grown by free interface diffusion at 20 °C.

Protein crystals will also be grown of calmodulin, the most important member of the family of intracellular calcium target proteins that regulate motion and development in animals and plants. By comparing the atomic structures of plant and animal calmodulin, scientists can learn how chains of amino acids fold together to form a particular protein. Hitherto, it has been impossible to grow high-quality crystals of plant calmodulin on Earth. These crystals will be grown by the hanging drop and liquid diffusion methods at 4 °C. ●

Separating Biological Materials

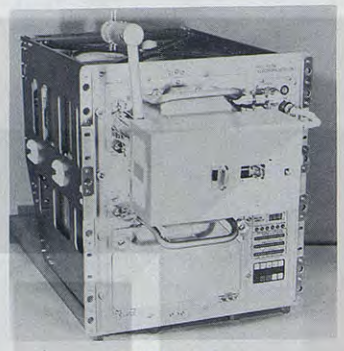
Electrophoresis in free-flowing solution is a unique process that separates biological materials into individual components using an electric field. For example, to obtain pure insulin-producing cells needed for the treatment of diabetes, the cells must be extracted from other cellular components. An electric field applied to a mixture of cells can fractionate the cell mixture from which insulin can be obtained. Then, the desired product is collected for analysis or use in a particular pharmaceutical product.

While Earth-based electrophoresis provides good separations for some products, the purity of some materials can still be improved. In Earth's gravity field, convection currents and sedimentation often remix compounds, preventing production of suitable quantities of very pure substances. Previous microgravity experiments have demonstrated that free-flow electrophoresis is altered in microgravity where convection and sedimentation are restricted.

Two electrophoresis facilities with different designs will be flown on IML-2. They provide two methods, continuous flow (or free-flow electrophoresis) and isoelectric focusing. In each electrophoresis facility, a solution flows through a thin, rectangular chamber. When a protein solution or cell population is injected into a flowing buffer solution, an electric field can be used to separate proteins as they travel through the chamber. IML-2 scientists will build on the heritage of continuous flow electrophoresis operations in space by studying a variety of biological materials and further characterizing this type of processing and the physical properties that affect it.

Free-Flow Electrophoresis Unit (FFEU)

Payload Developer: NASDA



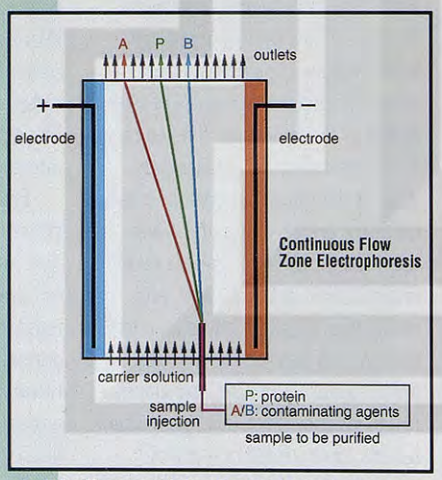
FFEU hardware

Four different biological materials will be tested separately in the electrophoresis unit. They are injected into one of three types of buffer solutions contained in separate tanks. One type of buffer solution is specifically used to test isoelectric focusing by creating a pH gradient in the flow for a separation of small charge differences. An electric charge applied in the main separation chamber causes the individual components in each mixture to separate into substreams, and the flow will be divided into up to 60 separation collection tubes. At the bottom of the separation chamber, a window linked by optical fibers detects the sample streams in different intensities of ultraviolet light passed by the sample. The crew in space and scientists on the ground examine the intensity and monitor the readings.

Gravitational Role in Electrophoretic Separations of Pituitary Cells and Granules

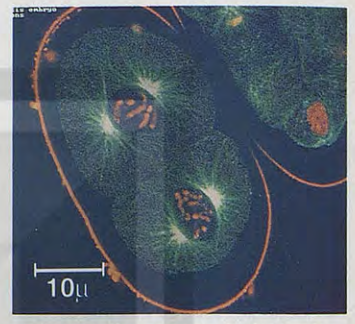
Principal Investigator:
Dr. W.C. Hymer

Growth hormone and prolactin are produced continuously by the pituitary cells throughout life. Growth hormone not only promotes growth of long bones during adolescence but also plays an important role in adults. High blood levels of the hormone in adults will increase muscle mass and promote breakdown of fat. Prolactin participates in the control of the immune system. The growth hormone and prolactin systems consist of pituitary cells, which produce the hormones; secretory granules inside the cells, which store the hormones before release into the bloodstream; and the hormones themselves.



In this diagram of the electrophoresis process, the mixed sample is separated into three bands by the electric charge as it flows through the chamber.

For this experiment, electrophoresis will be used to separate the hormone system components to determine whether separation in microgravity is superior to separation on Earth. In addition, since microgravity has been shown to negatively influence parts of this system, electrophoresis will be used to help determine how the pituitary growth hormone and prolactin-containing cells/granules are affected by spaceflight. Rat pituitary cells will be loaded in three culture chambers. Periodic sampling of the products from cells stored in the first chamber will permit postflight analysis of microgravity-induced structural and functional changes in growth hormone and prolactin molecules.



The genetic components that make up these nematode eggs will be separated using the FFEU. The chromosomes are stained orange by a fluorescent reagent. Analyzing the ultra-pure samples of the nematode chromosomes will help scientists with genetic mapping. ***(Scale bar is 10 microns.)***

Cells carried in the second chamber will be separated into 30 tubes by electrophoresis in flight. These 30 cell samples will be cultured in microgravity to determine the functional capabilities of the cells after separation. Cells from the third chamber will be broken apart, and the prolactin and growth hormone granules will be separated by electrophoresis. After separation, these granules will be frozen for postflight analysis to determine if internal changes occurred during the first 5 days of the flight.

Separation of Chromosome DNA of a Nematode, *C. Elegans*, by Electrophoresis

Principal Investigator:
Dr. H. Kobayashi

A sensitive electrophoretic method, called isoelectric focusing, is applied with the FFEU to separate chromosome deoxyribonucleic acid (DNA) from a nematode. The chromosome DNA cannot be separated using standard electrophoresis because it has a constant electric charge density, so the DNA will be separated based upon its molecular size. Since there is no gravity-induced convection or mixing, electric charge should be dominant, resulting in a successful separation. The ability to separate chromosomes and test the method

in space may help solve problems in genetic mapping and molecular biology. Concentrated suspensions of chromosome DNA will be separated on orbit, and the chromosome fractions will be retrieved and analyzed by standard genetic and biochemical tests.

Experiments Separating the Culture Solution of Animal Cells in High Concentration Under Microgravity

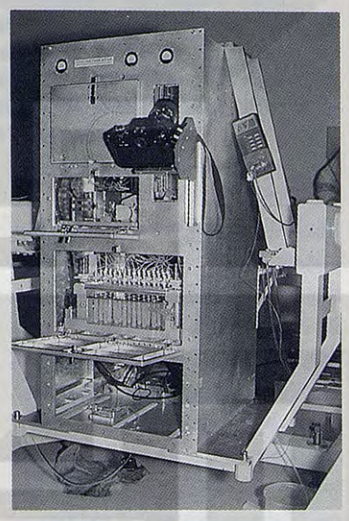
Principal Investigator:
Mr. T. Okusawa

This experiment grows animal cells in cultures and then separates their cellular secretions from the rest of the culture solution. Two fundamental aspects of pharmaceutical production — the rate of separation and the amount of the separated product — may be improved by space processing. Animal cells synthesize valuable medical drugs, and a recent method for culturing animal cells on the ground is being used to grow cells at 10 times the previous rate. However, the substances must be further refined to obtain a pure pharmaceutical product in larger quantities. Electrophoretic separation of the cells in space may result in larger amounts of a purer product. In addition, previous experiments indicate that the cells may secrete at faster rates during shorter periods in microgravity.

One type of hybrid animal cell in the Cell Culture Kits (CCK) will be incubated and grown in the Thermoelectric Incubator (TEI) for 5 days. *(See TEI and CCK section, page 30.)* Then the highly concentrated cell solution will be injected into the FFEU for separation of the secreted product. The sample will be separated under three different conditions. Finally, fractions of the sample separated under the most suitable condition of sample separation will be collected and frozen for postflight analysis. ●

Applied Research on Separation Methods Using Space Electrophoresis
Recherche Appliquée sur les Methodes de Separation en Electrophorèse Spatiale (RAMSES)
Payload Developer: CNES

The RAMSES electrophoresis unit has a special transparent chamber so that scientists can monitor the progress of samples as they are processed. The chamber has 40 outlets for collecting separated samples. To analyze the fractions, the concentration of each fraction is monitored continuously with an ultraviolet photometer that allows scientists to deduce the sample concentration by measuring how strongly light is absorbed by the samples. Samples will be photographed, and some will be collected and refrigerated for analysis on Earth.



After biological substances are exposed to an electric field, the ultrapure components will be collected in the tubes in the bottom compartment of the RAMSES facility.

There have been extensive ground-based research and applications of the electrophoresis process. Here, research is being conducted at the French National Scientific Research Center's Chemical Engineering Laboratory in Toulouse, France.

Optimization of Protein Separation

Principal Investigator:
Dr. V. Sanchez

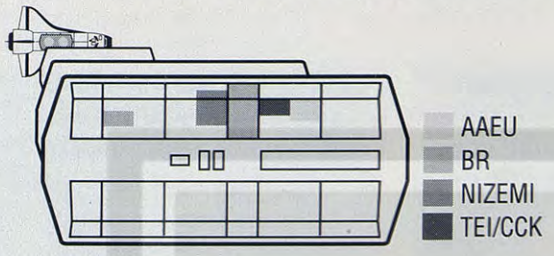
During this investigation, two series of experiments will evaluate the quality of protein purification in microgravity. First, a mixture of two colored proteins, easily separated on Earth, will be treated using the same electric field strength and flow rates required for separations on Earth. Then, a mixture of two colorless proteins, too similar to be easily distinguished on Earth, will be separated using four different combinations of electric field strengths and flow rates. After observations, a crewmember will store the best samples. In the second set of experiments, an industrially produced protein preparation, which is difficult to purify on Earth, will be separated at two concentrations. Samples will be returned for postflight analysis.

Electrohydrodynamic Sample Distortion

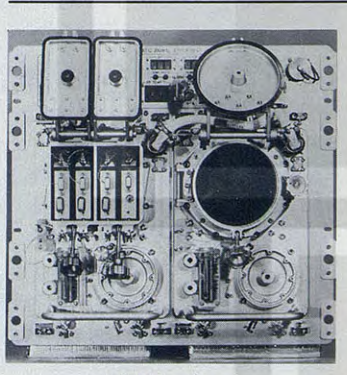
Principal Investigator:
Dr. R. Snyder

The factors that govern space-based electrophoresis must be more fully understood before highly concentrated samples can be processed on a large scale. Past continuous flow electrophoresis experiments exhibited electrodynamic sample distortion when the electrical properties of the sample and buffer did not match. To understand these processes, a suspension of spherical latex particles will be injected in place of the proteins, and an alternating electric field will be used. A thin sheet of light will illuminate the chamber cross section so that a crewmember may view and photograph any distortions to the flow of the latex particles.

Scientists will examine how much the shape of the sample flow is modified by the electric field, the flow of the carrier solution, and variations in the electrical conductivity of the solution. Two different samples will be used to show the effect of the latex concentration. Electrohydrodynamic effects are more predominant in space, where convection caused by buoyancy is virtually eliminated. Photographs will be made to provide data sample flow distortion; no collections will be made since the latex will not undergo any separation. ●



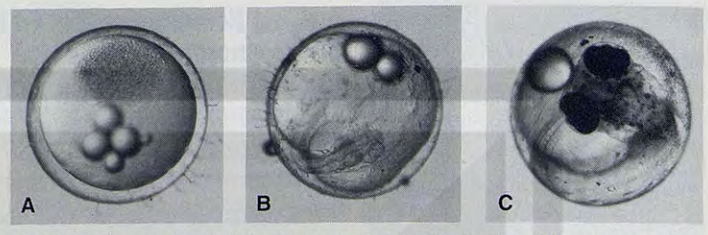
Aquatic Animal Experiment Unit (AAEU)
Payload Developer: NASDA



AAEU hardware

This aquarium, which was flown successfully on the Spacelab J mission, consists of two independent life-support systems, called fish and aquarium packages. Using this unit, scientists can study small aquatic animals for the duration of the mission. It permits observations of spawning, fertilization, embryonic stages, vestibular function, and behavior in microgravity. Animals, such as newts, live in four cassette-type aquariums, and there is a water tank designed for fish. A special life-support system supplies oxygen, removes carbon dioxide and waste (such as ammonia and organic substances), and regulates temperature from 15 to 25 °C. The crew can view the animals through a window and access them via a port.

A video system can be attached to the viewing port for recording observations of animal behavior, such as swimming patterns. Closeup observations can be made of fertilization and embryonic development. These images, along with housekeeping data on water temperature and pressure and other parameters, are downlinked to scientists working on the ground.



(A) Twelve hours after fertilization, a mass of cells clusters at the upper portion of the medaka egg. These cells will later form the embryonic body. (B) By 2 days, the primordial brain structure and optic buds have appeared, and the heart is pulsing. (C) A 4-day-old embryo has marked black eyes, and embryos continue to develop until around 8 days after fertilization, when they should hatch. Scientists want to learn if microgravity affects any of the development processes from fertilization to hatching.

Mechanism of Vestibular Adaptation of Fish under Microgravity
Principal Investigator:
Dr. A. Takabayashi

Space motion sickness is experienced by half of all human space travelers and has also been observed in several other species. This experiment is an extension of the carp experiment flown on Spacelab J and further explores the hypothesis that space motion sickness is caused by conflicting messages from the eyes and the otoliths, tiny organs in the inner ear that help animals sense their position relative to Earth's gravity field. To clarify the role of otolith asymmetry in this process, fish with surgically produced asymmetrical otoliths will be used as a model.

Medaka fish living in the AAEU will be observed to discern how microgravity affects their vestibular system, swimming patterns, mating behavior, and egg development. In this photograph of medaka fish (taken on Earth), a cluster of eggs is visible on the belly of the female fish.

Goldfish have two vestibular organs. Operations will be performed from 6 months to 2 weeks before launch to remove one or more otoliths from five goldfish; a sixth goldfish with both otoliths intact will be flown. Video recordings will be made once a day while the fish are stimulated by light entering the aquarium. Swimming patterns and response to light (dorsal light response) will be analyzed to determine how the fish vestibular systems adapted in microgravity.

Early Development of a Gravity-Receptor Organ in Microgravity
Principal Investigator:
Dr. M.L. Wiederhold

Many organisms, including humans, sense gravity with the otolith organs. In this experiment, scientists observe how otoliths develop in newts. Animals of different sizes have otoliths with masses related to their body masses; however, scientists do not know how otolith sizes are regulated. If the regulation is based on weight, scientists expect to find larger otoliths in animals raised in microgravity.

This investigation will determine the developmental stage at which otoliths first appear, the rate of otolith production at different development stages, and the rate of calcification at various stages of development in space. Size of the otoliths and associated sensory

Newts living in the AAEU will also develop from fertilization in the mother to hatching, allowing scientists to study their development in microgravity and identify any changes in their gravity-sensing organs.

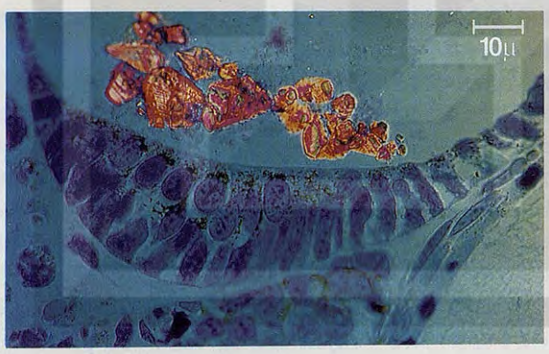
structures will be calculated by three-dimensional reconstruction of sections of the inner ear. The rate of calcification will be determined by labeling new calcium deposits with two different fluorescent calcium-binding dyes applied 4 days apart. Otolith function will be assessed by examining the newts' vestibular-ocular reflex. Scientists will also study the developmental sequence of the formation of receptor structures that sense angular acceleration in gravity. Data from newts flown in microgravity will be compared to controls on the ground, to embryos fertilized 3 to 5 days before launch, and to newt eggs fertilized on orbit. By comparing the groups, scientists can determine if otoconial formation proceeds normally in microgravity, and if not, whether 3 to 5 days of development before microgravity exposure can normalize development.

Fertilization and Embryonic Development of Japanese Newts in Space

Principal Investigator: Dr. M. Yamashita

Some previous experiments have indicated that gravity affects amphibian eggs before their first cleavage. A single egg divides into many cells, and those cells differentiate to form organs and function as a living system. Gravity is one factor that regulates this process, and by studying cell differentiation in microgravity, scientists may be able to determine the effects of gravity on cells at early developmental stages.

Egg laying is induced by hormone injection in adult female Japanese newts that were collected during hibernation before the mission. Half of the newts are treated with the hormone just before launch, and the others are exposed to the hormone in orbit. Approximately 2 to 3 days after these treatments, the female newts will lay eggs fertilized by sperm stored in their bodies. The crew will observe and document the eggs with magnified video images, tracking newt development for the rest of the mission. Some newts will be preserved at specific development stages, while some embryos will not be fixed so that further development can be studied postflight. Dr. Yamashita's experiment will use the same four adult newts as Dr. Wiederhold's experiment.



These bright yellow stones (otoconia) are sitting on top of the sensory-receptor cells inside the gravity-sensing organ of a newt larva. By examining newts at various developmental stages, scientists can determine if microgravity affects otolith development.

Mating Behavior of the Fish (Medaka) and Development of their Eggs in Space

Principal Investigator: Dr. K. Ijiri

This experiment studies the swimming patterns, mating behavior, and egg laying of small freshwater fish. It examines the early development of the eggs, determining whether all the processes from fertilization to hatching take place normally in microgravity. Fish require more study because they are an important component of the ecological life-support systems being considered for long-term human stays in space.

Usually, fish swim in loop patterns when they are exposed to microgravity, but previous experiments during short microgravity exposures on parabolic flights aboard aircraft have established that a special breed of this species of fish may not exhibit this behavior. This experiment will examine whether this strain of fish swims normally without looping over a longer period in microgravity. Swimming patterns and mating behavior of adult fish will be recorded on videotape. The crew can observe spawned fertilized eggs as a cluster on the belly of the female. When spawned eggs are observed on one day, usually the same fish pair will mate on the next day. Mating behavior will be take place within 2 hours after the light is switched on in the aquarium. Thus, video started immediately after the light is turned on can record fish mating behavior. The spawned eggs will eventually leave the female body and pass through a membrane to an area separated from the adult fish, and video observations of egg development will continue at predetermined intervals. The fry are expected to hatch approximately 8 days after spawning, and their swimming behavior will also be recorded on videotape. These will be some of the first specimens studied that have undergone the entire development process in weightlessness. Postflight, scientists will continue to study the swimming patterns of adult and fry, and genetic studies of their offspring will be carried out. ●

Biorack (BR)
Payload Developer: ESA

Biorack is a multipurpose facility for studying the effects of microgravity and cosmic radiation on isolated cells, tissues, bacteria, small animals, and plants. While the hardware used in each study may be unique, all experiments fit in either 186 Type I containers (about the size of cigarette packs) or 17 Type II containers (about the size of pint ice cream cartons); therefore, multiple experiments can be carried out in the facility at the same time. Since specimens may evolve through several stages of their lives (or in some cases, several generations) over the course of the mission, scientists can learn a great deal about the effects of microgravity and cosmic radiation on living tissues. Previous Biorack flights have included samples ranging from frog eggs to mouse bone cell cultures. This mission will repeat experiments on those samples and also explore the effects of gravity and radiation on human cells, animal cells, yeast, bacteria, fruit flies, sea urchins, and plant seedlings.

IML-1 Payload Specialist Dr. Roberta Bondar works with a sample in the Biorack glovebox.

To prevent sample contamination or the release of liquids within Spacelab, most Biorack crew operations are performed in an enclosed working area called the Biorack glovebox. Using gloves that extend into the sealed work area, crewmembers can handle the specimens. To enhance observation and documentation of samples, a still camera or a video camera can be mounted on the glovebox. Discriminating between the influence of microgravity and other space conditions (such as radiation) is accomplished by exposing duplicate samples to a simulated 1-g environment in centrifuges inside incubators. Additional controls are provided by experiments conducted concurrently on the ground in a model of Biorack that is identical to the flight unit. Flight samples are either cooled at 4 °C, frozen, or returned at ambient temperature for postflight analysis.

Antigen Presentation and T-Cell Proliferation in Micro-G (Antigen)
Principal Investigator: Dr. A. Cogoli

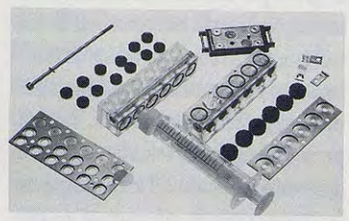
When antigens, such as toxins or bacteria, enter the body, fragments of the antigen are retained on special immune cells. T- and B-cells recognize the antigens via their surface receptors, and the T-cells help stimulate the B-cells to proliferate and divide into cells that secrete antigen-destroying antibodies. This experiment examines how T-cells recognize and respond to specific antigens. The antigen responsiveness will be compared to the mitogen stimulation of T-cells on the same flight. Cells in cultures will be incubated with an antigen or mitogen, labeled with a tracer, and preserved for postflight analysis.

Lymphocyte Activation, Differentiation, and Adhesion Dependence on Activation (Adhesion)
Principal Investigator: Dr. A. Cogoli

The *in vitro* activation of human lymphocytes by concanavalin A has been measured on different spaceflights. Several times, the activation of T-lymphocytes and monocytes in suspension was found to be reduced by more than 90 percent. However, in an experiment performed on SLS-1, activation and production of gamma-interferon more than doubled with cells attached to microcarrier beads, although lymphocytes are non-adhesive cells. It is believed that the depression of activation of cells in suspension is caused by an impairment of the macrophage function (the ability of immune cells to destroy bacteria and other substances) rather than by an impairment of the lymphocytes. This experiment may provide insight into the complex mechanism of lymphocyte activation, which is essential for immune defense. Cells in suspension or attached to microcarrier beads will be incubated, activated with a mitogen, labeled with a tracer, and preserved for postflight analysis.

Lymphocyte Movements and Interactions (Motion)
Principal Investigator: Dr. A. Cogoli

The activation of T- and B-cells in the immune system is based on the exchange of messages through cell-cell contacts and through soluble factors called lymphokines. This experiment examines whether cell contacts can take place in microgravity. Postflight microscopic evaluations have shown that aggregates are formed, and observations indicate that adhesion-dependent cells have attached to beads in microgravity. A recent sounding rocket experiment provided direct evidence of cell contacts, as movements of cells in microgravity were detected by real-time microscopic observations. These cell interactions are critical for many biological functions, such as antigen recognition by immune cells. Lymphocytes will be activated in the Biorack glovebox and incubated and transferred to the NIZEMI for microscope observations.
(*See Motion experiment, NIZEMI section, page 29.*)



Each Biorack experiment team develops its own hardware. The individual hardware for the Cytokines experiment (top) is designed so that samples can be removed from the container via a syringe. Most experiments fit into Type I containers (bottom, with the Phorbol experiment hardware); some require a larger Type II container.

Effect of Microgravity on Cellular Activation: The Role of Cytokines (Cytokines)

Principal Investigator:
Dr. D. Schmitt

Previous experiments have shown that the production of the cytokines interleukin-1 and -2 (substances that promote cell division) is inhibited in microgravity. Cytokines are necessary if cells are to activate and proliferate to fight disease. The efficiency of T-lymphocyte and monocyte activation will be studied by measuring the production of the specific cytokines interleukin-1 and -2 and gamma-interferon.

Cells are incubated in microgravity and on the 1-g centrifuge. Approximately 15 hours after activation, cultures are filtered, supernatant is isolated, and cells are fixed. Postflight, scientists will compare the synthesis of the different proteins in the cells, and activation will be measured by the level of interleukin-1 and -2 production. In addition, they will measure glucose consumption in the culture media to determine the rate of cell growth.

Effect of Microgravity on Cellular Activation: the Role of Cytokines (Phorbol)

Principal Investigator:
Dr. D. Schmitt

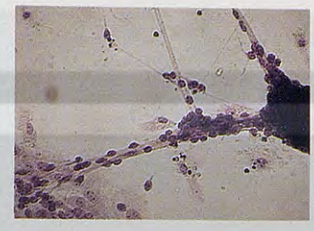
Immune cells could be activated to divide and differentiate through the binding of phorbol esters (organic compounds formed by the reaction of acids and alcohols) to a membrane receptor, which in turn activates the protein kinase C (PKC) signaling pathway. If the ester does not bind to the proper protein receptors, cellular differentiation slows down. Previous experiments in microgravity have shown that microgravity influences cells undergoing differentiation.
A related experiment on the Soviet Cosmos Biosatellite 2044 showed a dramatic decrease in the substances, such as interleukin-1 and -2, that promote cell division in immune cells activated by phorbol esters. For this study, lymphocytes will be incubated in microgravity and on the 1-g centrifuge for 1 hour. Then, the binding is stopped and the cells are frozen. Postflight chemical analysis will reveal how effectively the phorbol esters bound to the intracellular receptor.

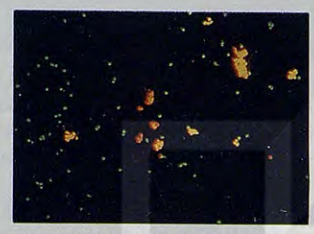
Cell Microenvironment and Membrane Signal Transduction in Microgravity (Signal)

Principal Investigator: Dr. P. Bouloc

Microgravity affects physical properties of fluids such as convection and sedimentation, and thus, cells and living organisms that are largely composed of fluids behave differently in space. Human lymphocytes (*in vitro*) are not activated by the usual inducers, and bacteria seem to be less sensitive to antibiotics. In both cases, there is a deficient interaction between an external product and the cell. These phenomena could be caused by differences in the immediate environment of the cell or by a microgravity-induced change in the structure of the membrane. This experiment will study these problems.

If carbon dioxide gas is not retained by the cells of the bacterium *Escherichia coli*, they are unable to grow. Weak convection in microgravity should accelerate the start of growth by minimizing the dispersion of carbon dioxide in space-grown cultures as compared to control groups on Earth. In a second experiment, scientists will measure the ability of bacteria to respond to certain activators in microgravity. Bacteria respond to modifications of the environment through systems composed of two proteins, a sensor and a receiver. Such systems respond to changes in osmolarity, pH, nitrogen, temperature, or chemical concentrations. If the phenomenon of non-activation is general, scientists should observe differences in activation between samples growing in microgravity and 1-g.





Many Biorack experiments study cells. (Top) The Aggregate experiment studies how primary mouse cells form aggregates and cable-like interconnections. (Bottom) Genetically engineered mouse fibroblast cells that express specific cell adhesion molecules (orange) form aggregates, while normal fibroblasts that do not express these surface proteins (green) do not aggregate. Such cells will be used to study sorting mechanisms during aggregate formation.

Effect of Stirring and Mixing in a Bioreactor Experiment in Microgravity (Bioreactor)

Principal Investigator: Dr. A. Cogoli

On Earth, some cells are not capable of spontaneous movement, so they sediment and form pellets if they are not mixed. Cells within the pellets quickly become depleted of oxygen and nutrients and are exposed to increasing levels of waste products. Lack of sedimentation and convection in microgravity favors the formation of oxygen and nutrient gradients as well as the formation of stationary films at the cell- solution interface. Therefore, a 1-g centrifuge, which is commonly used as a control for space experiments, may not be optimal for cell growth. It may be better to stir or mix solutions to achieve a homogenous mixture.

This experiment studies the effect of stirring and mixing on the growth characteristics of baker's yeast (*Saccharomyces cerevisiae*), which is sensitive to nutrient limitations such as glucose or oxygen. The yeast cells are contained in two special bioreactors; each fits into a Type II container and has a reactor chamber, mechanical components, and electronics. Three milliliters of yeast culture are incubated in the reactor chamber. Fresh medium will be pumped at constant flow rates from the reservoir bag to the reaction chamber. Cells and medium will flow out through a one-way valve into the waste reservoir so that the volume of the culture remains constant. The culture will be maintained at pH 4.5. Parameters of the chamber will not vary, resulting in a stable environment. The bioreactor will run automatically for 8 days, and data will be transmitted to the ground. Samples will be removed from the chamber on specified days and preserved for postflight analysis.

The Immune System and Microgravity

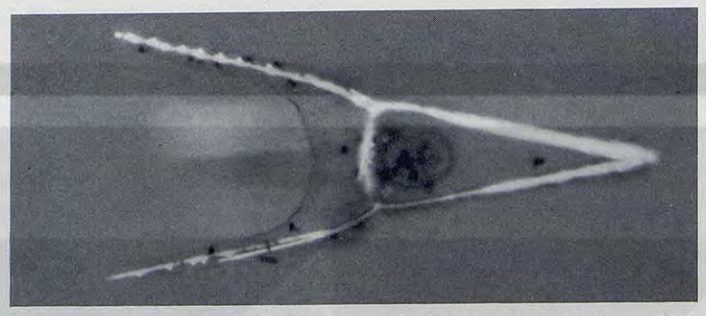
To counteract disease, our immune cells (such as T- and B-cells and other lymphocytes) multiply to fight bacteria or infection. Before these cells can fight disease, they must be activated and proliferate. Previous spaceflight experiments have indicated that *in vitro* lymphocyte activation by mitogens (substances that cause cells to divide) is depressed by more than 90 percent. If lymphocyte activation in space crews decreases during extended space missions, their immune systems may not work sufficiently to fight diseases. A number of the Biorack investigations explore processes such as cell communication, cell movement, and the interactions of antibodies to determine if they change the immune system's operation in microgravity.

Molecular Biological Investigations of Animal Multi-Cell-Aggregates Reconstituted under Microgravity (Aggregate)

Principal Investigator:
Dr. U.A.O. Heinlein

To form tissues, cells must recognize each other and interact to form specific patterns. On Earth, the processes of cellular recognition and interaction are difficult to study because gravity disturbs the cell surface interactions mandatory for optimal *in vitro* pattern formation. Instead of attaching to each other, as they do when forming a tissue, the cells rapidly attach to the bottom of the culture flask. In microgravity, cells should not move toward the bottom of the flask but remain suspended and reaggregate to form organized tissue-like cell layers.

The purpose of the experiment is to observe how primary cells, prepared from two mouse tissues (cerebellum and testis), reaggregate in microgravity. As they remain suspended and undisturbed, reaggregation to three-dimensional structures is more likely to depend solely on molecular cell surface parameters. The importance of such parameters will be studied in more detail by the use of genetically engineered heterologous cells that express special forms of adhesion molecules on their surfaces. Incubation, culture media exchange, and fixation will be performed in a semi-automatic incubation chamber. The cells will be returned to the ground for molecular and cytological postflight analysis.



A sea urchin embryo develops within a few days into a larva, the pluteus, which has a typical internal skeleton formed of connected spicules. These embryos and larvae are excellent candidates for studying biomineralization processes in microgravity and possibly even for understanding more about bone mineralization in humans. When viewed under a polarization microscope, the magnesium calcite skeleton behaves like a monocrystal and glows brightly inside the larva. The length of the pluteus is about half a millimeter.

Regulation of Cell Growth and Differentiation by Microgravity: Retinoic Acid-Induced Cell Differentiation (Mouse)

Principal Investigator:
Dr. S.W. de Laat

Mouse cells, a model system, will be exposed to retinoic acid (vitamin A group), which has a profound effect on early differentiation, particularly in pattern formation of limbs. The influence of microgravity on differentiation induced by retinoic acid and the proliferation of the mouse cells will be studied. The cells will be incubated on orbit in the Biorack, both in microgravity and in the 1-g centrifuges. Later, cells will be marked with molecular and morphological labels and preserved for postflight analysis.

The Sea Urchin Larva, a Potential Model for Studying Biomineralization and Demineralization Processes in Space (Urchin)

Principal Investigator:
Dr. H.J. Marthy

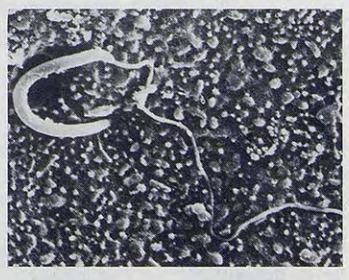
This experiment examines sea urchin embryos and larvae to determine if the mineralization process that creates the typical sea urchin larva skeleton is normal in space. It further examines the organism's development to see if the formed skeleton is stable or if there is a progressive loss of calcium and other minerals. This demineralization process, if it occurs, might be a good model for the loss of bone minerals experienced by humans in microgravity.

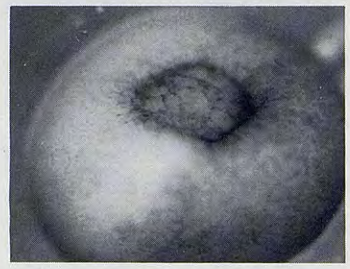
Containers with sea urchin eggs at two different stages of development will be placed in the incubator in microgravity and on the 1-g centrifuge. The swimming behavior of specimens in one container will be observed by microscope and recorded on video several times during the mission. Sea urchin larvae from all containers will be preserved at different developmental stages. After the mission, scanning electron microscope and X-ray microprobe analysis will be used to assess the mineral composition and content of the preserved skeletal rods.

The Effects of Microgravity and Varying 1-G Exposure Periods on Bone Resorption; an *in Vitro* Experiment (Bones)

Principal Investigator:
Dr. J.P. Veldhuijzen

Ground-based studies have shown that cartilage and bone in embryonic mouse long bones kept in tissue culture (*in vitro*) calcify more quickly under increased hydrostatic pressure and extra-g forces than under normal conditions. With normal experiment conditions, bone demineralization is decreased. Human bones being stressed in gravity react the same way. Recently, it has been shown that exposure of cultured mouse fetal long bones to 1-g forces during spaceflight prevented microgravity-related bone loss. This suggests that cultured embryonic mouse long bones can serve as a model for studies on the cellular effects of microgravity on bone mineralization and demineralization.





Amphibian eggs were successfully fertilized in space for the first time on a 1988 sounding rocket flight. The top photograph shows a sperm penetrating the egg. The bottom photograph shows the first toad gastrula (an early embryonic form) to develop in space. The egg was fertilized and developed during the IML-1 mission; this study will be continued during IML-2 with the Eggs experiment.

The Skeletal System and Microgravity

Previous data from crewmembers and other organisms have shown that the lack of gravitational force on bones causes demineralization, the loss of calcium and other minerals. Although calcium loss may level off during spaceflight, the likelihood that crewmembers will break weakened bones may affect their ability to function in Earth's gravity after an extended mission. Several Biorack experiments examine the skeletal system of various organisms to help determine the mechanisms involved in bone demineralization in microgravity.

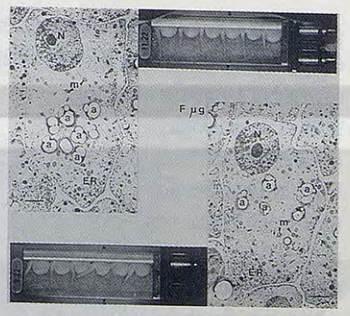
Scientists postulate that exposure to a short period of 1-g force during a 24-hour period of microgravity should be sufficient to prevent adverse microgravity effects on the skeleton. Cultures of long bones will be exposed each day to various periods (3, 6, and 12 hours) of 1-g forces. Postflight, scientists will study the cellular responses of bone-forming and bone-resorbing cells.

Investigation of the Mechanisms Involved in the Effects of Space Microgravity on *Drosophila* Development, Behavior and Aging (Drosophila)

Principal Investigator: Dr. R. Marco

Previous experiments have shown that the exposure of young fruit flies (*Drosophila melanogaster*) to microgravity results in numerous effects on their development, including an increase in the formation of eggs (oogenesis) and an increase in the time required to complete the development process. However, the aging process of adult flies in space is accelerated. During this long-duration flight, scientists will test the hypothesis that life shortening in space is linked to an increase of locomotor activity, which is accompanied by excessive respiration. This ultimately results in damage to mitochondria, the organelles that provide energy to the cell by the respiration process.

Fruit flies will be flown in space, and embryos will be preserved on specific days. Postflight, the fixed or frozen embryos (along with live adult flies) will be studied. Scientists will examine the flies' morphology, biochemical makeup, and behavior to determine the effects of microgravity on the genetic background, developmental processes, sexual and geotropic behaviors, and aging.



Lentil seedlings were grown either in microgravity or on a 1-g centrifuge in space. On the centrifuge, roots grew in the direction of the acceleration, but in microgravity, there was no preferential orientation of the root tips. Micrographs show gravity-sensing cells located at the extremity of the root.

The Role of Gravity in the Establishment of the Embryonic Axes in the Amphibian Embryo (Eggs)

Principal Investigator: Dr. G.A. Ubbels

The egg of the clawed toad, *Xenopus laevis*, rotates shortly after fertilization, its animal-vegetal axis parallel to the gravity field, with its pigmented pole upward. Previous experiments suggest that gravity cooperates with the sperm in the specification of the body axis. The time and pattern of subsequent cell divisions are crucial in this early phase of embryonic pattern formation. At first, the cells divide almost synchronously, making a "wave" of cell divisions over the egg. At later stages, the synchrony is progressively lost, with the cell population splitting into compartments, each with its own division rhythm that is related to the final fate of the cells. This experiment examines whether normal division synchrony in the early embryo is maintained under microgravity.

Frog eggs will be fertilized and incubated in automated hardware in microgravity, on the 1-g centrifuge, and in static containers on Earth. The embryos will be histologically fixed at the fourth and eighth cleavage. Postflight, the pattern of cell divisions, as well as the distribution of yolk granules and specific cytoplasmic localizations, will be determined in relation to axis formation.

Effect of Microgravity on Lentil Morphogenesis (Lentil)

Principal Investigator: Dr. G.E. Perbal

Gravity-sensing cells (statocytes) are located in a cap covering plant root tips. The organelles in these cells are polarized with respect to gravity. When the root is in the vertical position, the nucleus is always located in the apical (top) part of the cell, and voluminous amyloplasts (statoliths) sediment on large aggregates of endoplasmic reticulum located near the basal (bottom) cell wall. In microgravity, the polarity of the statocyte is perturbed, and consequently, root growth is modified. When the root is placed in a horizontal position the amyloplasts move toward the longitudinal wall but never touch the plasma membrane.

This experiment tests the hypothesis that the settling down of the statoliths on the endoplasmic reticulum is responsible for the regulation of root growth. Six different groups of lentil seedlings will be exposed to microgravity and then placed on the 1-g centrifuge (or vice versa). After photographs and real-time downlinked video data are used to examine the growth status of the roots, the seedlings will be fixed for postflight analysis.

Organism Development and Microgravity

Until spaceflight, organisms have always developed with a 1-g reference. What role does gravity play in directing cellular division and differentiation as cells form new organisms? When organisms mate and produce offspring in microgravity, will the offspring be normal? Scientists are just beginning to study these issues. The IML-2 experiments will help determine how organisms reproduce and develop without gravity and also give scientists greater insight into gravity's role in these processes.

Plants and Microgravity

Experiments on previous flights have shown that microgravity may affect plant behavior commonly observed on Earth. When there is no up or down, in which direction will plant roots grow? Scientists are still investigating this basic question, as well as trying to determine exactly how plants sense gravity on Earth. Biorack investigations study several species of plants to answer these questions and explore how plants grow in the space environment. These questions must be answered before plants can be grown as part of a controlled ecological environment needed for long-term stays in space.

Radiation in Space

Although Spacelab has special radiation shielding, cosmic radiation does penetrate the spacecraft. Previous investigations have shown that this radiation can be particularly damaging to single cells. Surprising results have also indicated that cells exposed to both radiation and the microgravity environment may suffer more damage than cells exposed to only one effect. One Biorack investigation is devoted to helping investigators distinguish which cellular changes are caused by radiation, microgravity, or both, and two others explore the effects of microgravity on cellular repair of radiation-induced damages.

Root Orientation, Growth Regulation, Adaptation, and Agravitropic Behavior of Genetically Transformed Roots (Transform)

Principal Investigator:
Dr. T.H. Iversen

Transformation of plant cells by strains of *Agrobacterium* causes dramatic changes in the metabolism of the transformed cells and in the physical characteristics of the intact plants regenerated from transformed cells. Wild type strains of *A. rhizomes* are known to induce growth of abundant transformed roots called "hairy roots." These roots have a high growth rate, branch out excessively, and in some cases do not exhibit gravitropism (curvature in response to gravity).

Three clones of transformed, agravitropic roots (those that grow in any direction) have been isolated. Normal gravitropic roots, which grow downward, will be used as the control. The goal is to test whether the growth of agravitropical roots on Earth is similar to that of normal roots grown in microgravity. In addition to the agravitropic roots, single transformed cells isolated from the same roots will be tested. These cells will be isolated as protoplasts (cells from which the walls have been removed). After retrieval, scientists will attempt to regenerate intact plants from the protoplasts. The roots and the regenerated plants will be analyzed to determine if microgravity alters the permanency of the genetic transformation. Containers of roots and protoplasts will be incubated in microgravity and then exposed to 1-g on the centrifuge. The plants' gravitropic responses will be observed in the photobox with time-lapse photography, and samples will be fixed at designated times. Both fixed samples and living roots and protoplasts will be returned to the ground for genetic analysis.

Plant Growth and Random Walk (Random)

Principal Investigator:
Dr. A. Johnsson

Experiments on Earth indicate that plants placed on clinostats and exposed to gravity levels higher than 1-g grow in a more "straight" fashion. Deviations are caused by spontaneous random movements and the nature of these growth movements can only be studied in weightlessness. Scientists have hypothesized that these movements can be described and treated as a random walk process (similar to molecular random motions in a liquid). The hypothesis can be tested by observing plant curvature in microgravity. This experiment will quantitatively observe root behavior and increase our knowledge of root growth dynamics.

Seedlings will be transferred to a photobox at about 11 and 17 hours into the mission, and time-lapse photography will go on for 35 hours. Other containers of seedlings will be exposed to 1-g on the centrifuge inside the incubator; at designated times, these seedlings will also be transferred to the photobox and photographed. Photos will provide the main information from the experiment, but fixed samples will also be returned to Earth for analysis.

Dosimetric Mapping Inside Biorack on IML-2 (Dosimetry)

Principal Investigator: Dr. G. Reitz

This experiment will document the radiation environment inside Biorack and compare the data with theoretical predictions and data from previous flight experiments. It will provide radiation baseline data for all the Biorack experiments to use to distinguish microgravity effects from radiation effects. Before launch, dosimeters will be placed in the Biorack stowage and overhead compartments. On orbit, dosimeters will be placed in static racks and on 1-g centrifuges inside the Biorack incubators and in coolers where samples are stored.

Efficiency of Radiation Repair in Prokaryotes (Repair)

Principal Investigator:
Dr. G. Horneck

Scientists hypothesize that microgravity may affect the ability of biological systems to repair and recover from radiation damage. The first step of the repair process is for the cell proteins to recognize damaged sites in the DNA. This process involves the initial random collision of molecules and may be gravity dependent.

The repair efficiency of irradiated bacteria (*Bacillus subtilis*) will be measured by studying their capacities to form microcolonies after radiation exposure. Various cultures of genetically well-defined bacteria will be used. These cells differ in their capacity to repair damage in their DNA. Cultures will be activated and incubated to initiate the repair process and growth of cells to microcolonies. After several hours of incubation, photographs will be taken of the microcolonies. Scientists on the ground will view downlink television to decide when the cells should be preserved. The kinetics and efficiency of DNA repair will be determined after the mission.

Radiation Repair Kinetics in Eukaryotes (Kinetics)

Principal Investigator:
Dr. G. Horneck

Although synergistic effects of microgravity and radiation exposure have been reported in living organisms, the mechanisms of this interaction are not understood. For example, the ability of cells to repair and recover after radiation damage in microgravity has not been explored. In this experiment, frozen human skin fibroblasts and bacterial cells will be exposed to ionizing radiation before flight to induce damage in their DNA (such as strand breakage in the double helix). The cells are launched in a frozen state to prevent spontaneous repair processes before the samples are exposed to microgravity on orbit. During the mission, the cells will be incubated at 37 °C for defined periods to allow enzyme systems to repair the damage. After incubation, samples will be frozen again to preserve the amount of damage left unrepaired. Post-mission, scientists can examine the DNA and compare the kinetics of repair in microgravity with that in 1-g conditions. ●

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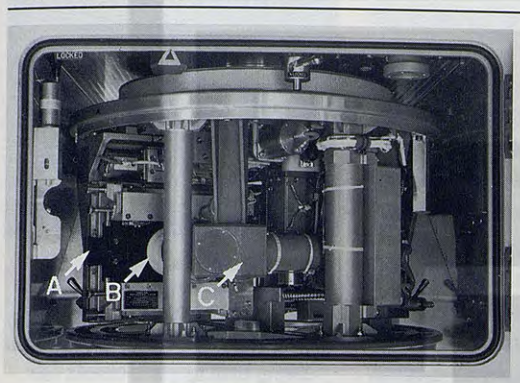


The NIZEMI facility centrifuge
(A) Sample Holder; (B) Microscope Objective; (C) Video Equipment

The NIZEMI allows investigators to observe detailed processes in biological organisms and chemical substances that may be affected by Earth's gravitational field. Microgravity is the only condition under which investigators can observe how organisms react to different artificial gravity levels (or accelerations) below 1-g. By exposing organisms to different gravity levels, investigators can determine an organism's sensitivity to gravity and learn more about the gravity-sensing mechanism.

Living organisms and inorganic samples are placed in the centrifuge, which creates gravitational force from 10^{-3}-g (1/1000 of Earth's gravity; about 10^{-6}-g in resting position) to 1.5-g. A microscope with up to 32X primary magnification for observing single cells and small organisms and a macroscopical observation unit for observing multicellular organisms are mounted on the centrifuge plate. Real-time video data will be downlinked to investigators on the ground or recorded for later analysis. Observing organisms during different accelerations provides information concerning the threshold value of gravisensibility, the minimum gravity level at which the organisms can perceive (identify) and show a reaction.

Gravisensitivity and Geo(Gravi)taxis of the Slime Mold *Physarum Polycephalum* (Slime Mold)

Principal Investigator: Dr. I. Block

The slime mold (*Physarum polycephalum*), a single-cell organism, moves on a vertical solid surface downward when in contact with air and upward when it is under water. This movement is accomplished through rhythmic contractions of an elastic wall (called the ectoplasm), a process not completely understood. The organism's reaction to light intensity and gravity, as demonstrated by changes in the rhythm of these contractions, has also been documented. At this point, no specific site for the organism's ability to react to changes in gravity has been found.

Previous Space Shuttle experiments confirmed the slime mold's sensitivity to gravity. This experiment uses the NIZEMI microscope to observe, for the first time, the reaction of the organism during a transition from 1-g to microgravity and also from 1.5-g to microgravity. Further, the NIZEMI will allow observation of the organism's movements at various gravity levels to determine the threshold of its sensitivity to gravity. These data will contribute to an understanding of how the creature senses gravity and may help locate the specific site of its ability to do so.

Influence of Accelerations on the Spatial Orientation of the Protozoan *Loxodes Striatus* (Loxodes)

Principal Investigator:
Dr. R. Hemmersbach-Krause

Previous experiments have demonstrated the ability of *Paramecium biaurelia* and *Loxodes striatus*, two unicellular organisms, to use gravity for their spatial orientation. *Paramecium* possesses no known site for perceiving gravity, while *Loxodes* has a specialized structure, called the Müller organelle, which may be responsible for the perception of gravity. It is believed that culturing *Loxodes* cells in microgravity should lead to morphological changes of the Müller organelle.

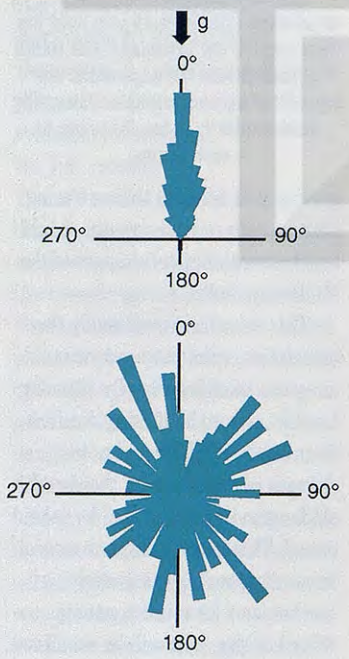
This microscopic image of a slime mold cell shows that it is composed of a network of protoplasmic strands. In the strands, a gel-like ectoplasm can be distinguished from a centrally located channel of fluid endoplasm that rhythmically changes its streaming direction. Scientists want if gravity plays a role in the streaming action and subsequent movement of the slime mold and how the slime mold senses gravity.

This microscopic image of the *Loxodes* shows three Müller organelles (diameter 10 μm) near the right edge of the organism. The round objects inside the organelles are crystals of barium sulphate. They may work similarly to the inner ear of vertebrates.

This experiment will study the orientation, velocities, and swimming tracks of *Loxodes*. By exposing *Loxodes* cells to increasing accelerations on the NIZEMI and noting changes in cell behavior, the threshold for graviperception can be determined. This information is essential for understanding the underlying mechanisms for sensing gravity. After landing, cells will be examined by electron microscope to determine changes in the structure of the gravity receptor and to obtain information on the biomineralization of single cells.

Gravitaxis of Unicellular Organisms

Free-living unicellular organisms, such as algae or ciliates, must orient themselves in their liquid environment, e.g., lake or ocean, in relation to light, chemical substances, and gravity to reach the best habitat for living and reproducing. Many cells show a positive or negative gravitaxis, i.e., they swim into or against the direction of gravity. This way, they can reach a suitable environment also in darkness. To learn more about the sensitivity of cells to gravity and the way they perceive gravity, some NIZEMI investigators examine the swimming behavior and movement of different uni- and multicellular organisms. All of these organisms have flown on sounding rockets and Spacelab missions, providing intriguing results.



(Top)
The unicellular flagellate, *Euglena*, under 1-g conditions before liftoff of the TEXUS sounding rocket, oriented itself precisely with the gravity vector.

(Bottom)
In microgravity, the movement vectors of the cells were distributed randomly.

Graviorientation in *Euglena Gracilis* (Euglena)

Principal Investigator:
Dr. D.-P. Häder

The microorganism *Euglena gracilis* depends on its ability to perceive gravity and light to position itself suitably in a column of water. Many competing theories attempt an explanation of this behavior, and some observers believe that a passive process (based on the shape, density, or motion of the cell body) regulates its sense of gravity. Other observers suggest that *Euglena* possesses a specific site within its body that in some way perceives Earth's gravitational field. The fact that short-term exposure to ultraviolet light and some heavy metal ions impair the organism's ability to orient itself properly also suggests that a specific physical site regulates the behavior.

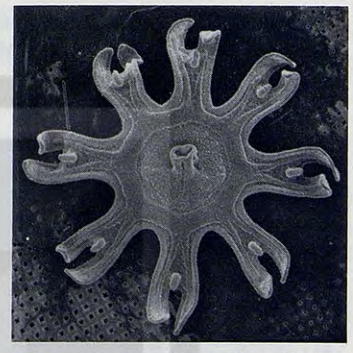
Study of these phenomena has been hindered by an inability to analyze the creature's behavior in the absence of Earth's gravity. Study in microgravity can help confirm findings obtained in labs on Earth. Using the NIZEMI, *Euglena's* threshold for sensitivity to gravity can be determined. Real-time video images will be recorded for later computer analysis. By observing how quickly the cells move in any direction in microgravity, experimenters can determine how much energy the organism needs to propel itself. Moreover, the overall effect of microgravity on the single cell can be assessed.

Effects of Microgravity on *Aurelia* Ephyra Behavior and Development (Jellyfish)

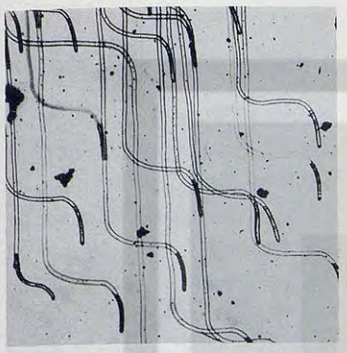
Principal Investigator:
Dr. D. Spangenberg

A related experiment flown on the Spacelab Life Sciences 1 mission revealed that jellyfish polyps metamorphosed to form ephyrae in space, but the behavior of the ephyrae was modified during the mission, whether they developed in space or on Earth. Many ephyrae circled or looped while swimming and froze when pulsing stopped. They did not orient themselves as they do on Earth, where they sink mouth-downward when they stop pulsing. On IML-2, the g-threshold for normal pulsing/swimming/orienting behavior of ephyrae will be determined and tracked to see if the g-threshold changes over several days in space. Results from the IML-2 mission will be used to improve scientists' understanding of the effects of microgravity on developmental processes of animals and the role of gravity in the behavioral and developmental responses of organisms on Earth.

Ten jellyfish samples will be flown, with ground controls for each. Six samples of ephyrae from Earth will be used for behavior studies. Three samples will be videotaped early in the mission and again several days later. Of this group, four ephyra samples will be maintained at microgravity, and two ephyra samples will be maintained at 1-g; two of the microgravity samples will have no gravity-sensing organs (statoliths). These samples will be exposed to different g-levels to determine the g-threshold for normal behavior. Four polyp samples will be exposed to iodine, which will cause them to form ephyrae in space. Two samples will be maintained at microgravity, and two will be kept at 1-g. These samples will be videotaped at regular intervals so that the developmental stages of the ephyrae can be compared. G-thresholds will again be determined by exposing the jellyfish to different g-levels and observing their behavior. The gravity receptors and muscles of organisms that develop during the flight will be examined postflight to determine the presence and nature of any abnormalities.



This ephyra has a central mouth and eight arms, each with one gravity receptor. The muscle system circles the mouth and extends into each arm.



A bundle of *Chara* rhizoids that normally grow straight down was rotated by 90 degrees several times for many hours on Earth. The rhizoid tips always changed their growth direction back to the vertical.

Gravireaction in *Chara* Rhizoids in Microgravity (Chara)

Principal Investigator:
Dr. A. Sievers

Chara is a green alga that adheres to the substratum by single cells called rhizoids. These tube-shaped, root-like organs grow only at the cell tip and react to gravity using membrane-enclosed crystals of barium sulfate (statoliths). The statoliths sediment on the physically lower cell flank when the rhizoid is tilted from the vertical. Thus, they help the cell orient itself in relation to gravity. In Earth's gravitational field, it has not been possible to determine the minimum level of sensitivity for gravity. This investigation with NIZEMI will determine the threshold values and the minimal amount of gravitational force necessary for the rhizoids to react gravitropically.

In vivo video microscopy will be used to observe the behavior of statoliths in microgravity. During these observations, statoliths will be exposed to stimuli of varying strengths and durations and in different directions in relation to the rhizoids' length axis. A sample will be labeled by the actin-binding drug phalloidin to observe the microfilament system where the statoliths are suspended. Knowledge of rhizoid growth and structural organization in microgravity, as well as information on the statoliths' movements and the reactivity of the rhizoid to the stimuli, will help scientists understand how sensitive single cells are to gravity and how they use this signal to orient growth.

Gravisensitivity of Cress Roots (Cress)

Principal Investigator:
Dr. D. Volkmann

Twenty years of investigations have provided detailed knowledge of how the cress root perceives and reacts to gravity. For the seedling, gravity sensing is crucial for survival, and previous experiments have shown that as little as a half-second's exposure to gravity causes plant roots to respond. As we consider raising plants for food and oxygen in space, an understanding of the relationship between gravity and plant growth will be required.

Combining data from NIZEMI's video microscope and from chemically prepared root samples, investigators will try to determine the threshold of the cress root's sensitivity to gravity and to discover the minimum dose of gravity the plants can perceive. After stimulation on the centrifuge, graviresponses of samples will be recorded, and some samples will be fixed for postflight examination with an electron microscope. Future experiments may reveal whether cress roots can "remember" receiving several tiny doses of gravity that fall below the threshold dose.

Lymphocyte Movements and Interactions (Motion)

Principal Investigator: Dr. A. Cogoli

This experiment examines whether cell contacts can take place in microgravity. Lymphocytes will be activated in the Biorack glovebox and incubated for a specified duration. Then, they will be transferred to the NIZEMI for incubation at different gravity levels. The crew will observe the cells' movements and contacts using the NIZEMI microscope, and views of the cells will be televised and downlinked to scientists on the ground. (*See Motion experiment, Biorack section, p.22*)

Convective Stability of a Planar Solidification Front (Moni)

Principal Investigator:
Dr. K. Leonartz

Many materials are produced from a melt; commercially, the most important are metals, and the solidification process plays an important role in determining their properties, including strength. This process is influenced by gravity, the concentration of the mixture, and the temperature gradient and speed at which it forms a solid.

Low-gravity experiments can help scientists understand the solidification process, which will help improve materials in the future. This experiment tests a mathematical model that allows the *a priori* calculation of the onset of convection, a fluid flow caused by density gradients in the melt. This convective fluid flow changes the properties of the melt and thus the resulting solid. A two-component mixture of succinonitrile-acetone, which solidifies like metal, will be used. This material is transparent, which allows the NIZEMI optical system to be used for real-time observations of the solidification process as it occurs in low gravity. ●

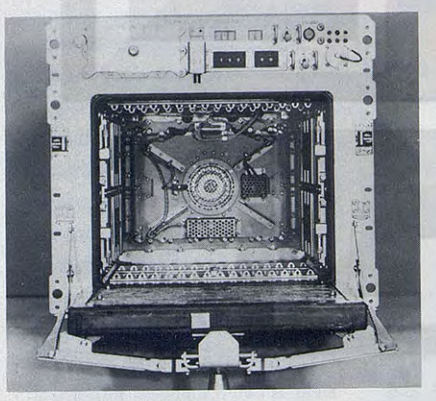
Cytoskeleton and Graviperception

In many multicellular organisms (plants and animals), there are specialized cells or organs that are responsible for perceiving gravity. Within a cell, the physical parameter (direction and intensity) of gravity is transformed into an intracellular signal that can be set off against other signals (e.g., light and chemicals) and can be transduced to other cells where the visible reaction (e.g., the bending of a plant root) occurs. Recent investigations performed in sounding rockets and on other spaceflights led to the hypothesis that the dislocation of slightly heavier organelles such as starch grains or barium sulfate crystals hanging in a network of protein filaments (cytoskeleton) and electrical changes in membranes as well as special ions are involved in signal transformation. Two NIZEMI experiments with plants should increase scientists' understanding of these mechanisms, which have been studied intensively on Earth and in space.

Thermoelectric Incubator (TEI) and Cell Culture Kits (CCK)

Payload Developer: NASDA

This general-purpose incubator maintains constant temperature, humidity, and carbon dioxide concentration, providing an environment for cultures of mammal and plant cells. The incubator will be operated at ~37 °C. For IML-2, three different types of Cell Culture Kits are used to support cell culture and electrophoresis experiments with internal volumes of 20 milliliters that will sustain samples of animal cells. The Petri dish type chambers are used for slime molds and plant cells. Scientists can observe the dynamics of cell growth, extract materials produced by the cells, and fix cells for inspection postflight. The animal Cell Culture Kits have transparent windows for microscope observations of cell cultures grown in orbit. A 35-mm camera will attach to the microscope to make still photographs of the samples. For the slime mold culture, a video system will record and downlink real-time images of specimens.



TEI hardware

Gravity and the Stability of the Differentiated State of Plant Embryos

Principal Investigator: Dr. A.D. Krikorian

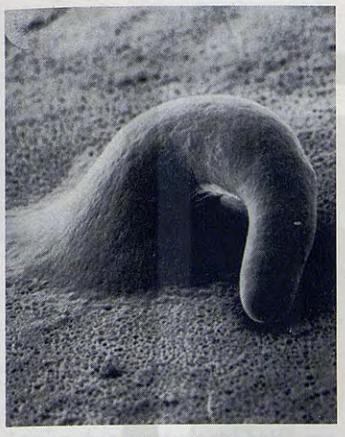
Space experimentation suggests that, while embryogenesis from totipotent cultural (asexual) cells of plants proceeds *in vitro* in microgravity, the degree and rate of development are both altered. Significant anomalies in the status and behavior of the nucleus of cells that make up the embryo have also been observed, including the fracturing of chromosomes and changes in their structure. This experiment uses aseptically cultured plant cells to validate and extend earlier work by testing and profiling critical stages in somatic embryogenesis. Specifically, it examines the effects on growth and differentiation of embryogenic plant cells and on mitosis and chromosome behavior. The information sought is not only of fundamental importance for plant cell biology and development but also is pivotal to implementation of futuristic plant-based biotechnologies in space.

The experiment uses daylily (*Hemerocallis*) and carrot (*Daucus carota*) plant cells as test systems. Both Petri dishes and liquid cell chambers are used as the growing vessels, thus allowing two basic types of culture environments to be evaluated. Cells with the ability to develop into embryos will be kept inactive by culture medium composition until they are in space and will be activated by modification of their nutrient status through changes in their metabolism. Both chemically fixed and live somatic embryo cultures will be returned to Earth for detailed cytological and postflight grow-out analysis.

Effects of Microgravity on the Growth and Differentiation of Cultured Bone-Derived Cells

Principal Investigator: Dr. Y. Kumei

This experiment compares functional differences in cultures of bone (osteogenic) cells exposed to 1-g and microgravity and investigates what genes are responsible for any differences. The search for genes that are specifically expressed or suppressed in microgravity can only be conducted during spaceflight. Osteogenic cells will be derived from young adult rodent femurs, which are sensitive to the unloading of gravity on the skeletal system. The cellular nucleic acids are harvested on orbit and undergo postflight analysis. The ultimate goal is to clarify the mechanism of osteoporosis induced by spaceflight. Eventually, this knowledge may be used to benefit the health of future space crews, to prevent bone disease on Earth, and to improve therapy for bed-rest patients who experience similar bone demineralization.



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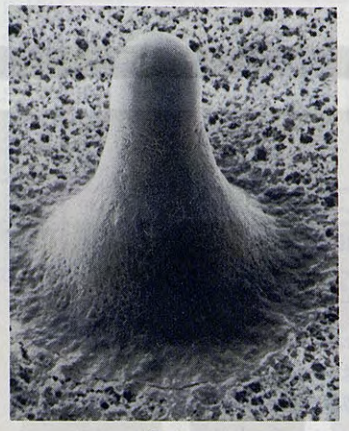

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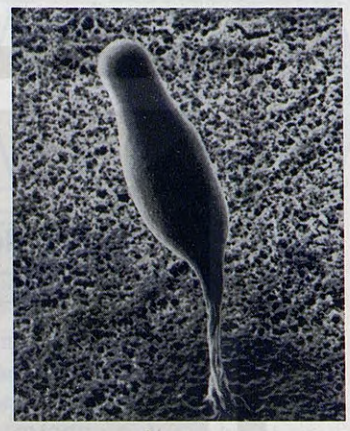


Sorogen

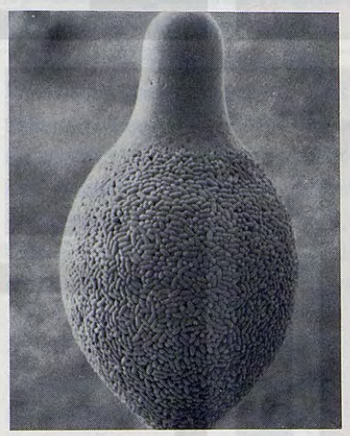
These scanning electron microscope images show the morphogenesis of a slime mold.

Differentiation of *Dictyostelium Discoideum* in Space

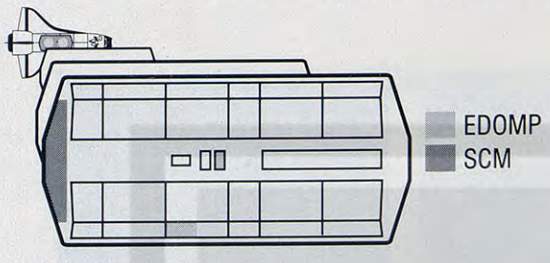
Principal Investigator:
Dr. T. Ohnishi

Slime molds (*Dictyostelium discoideum*) are found among decaying forest leaves and in topsoil and emerge from spores. During cell differentiation, the spores show very distinct morphological structures at various stages of cell division. The cellular differentiation of slime molds has been studied extensively on Earth, and this experiment should provide insight into how microgravity and radiation stress cells in space and affect their genetic expression and morphology. A radiation-sensitive strain and a wild-type strain for DNA repair against radiation damage will be used to help distinguish between the effects of microgravity and cosmic rays.

The organisms will be grown in plant cell culture chambers. In space, culture media will be added to activate the spores, which will be kept at 22 °C for 5 days in the Biorack incubator. A video camera attached to the culture chamber is used to observe and record cell morphology during cell growth, aggregation, and differentiation. After the flight, the viability of the spores that formed in space is evaluated, and radiation effects are determined by comparing the two types of slime molds. ●



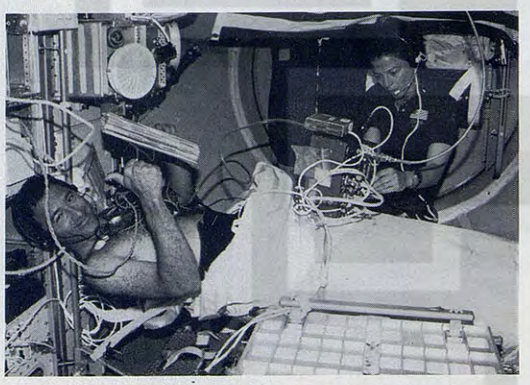
Young fruiting body



Extended Duration Orbiter Medical Project (EDOMP)

Payload Developer: NASA

The goal of the EDOMP is to maintain crew health and safety during 13- to 16-day missions aboard the Space Shuttle. A series of investigations has been designed to assess the medical status of the crewmembers and the environment where they work. One EDOMP investigation tests a treatment to counteract negative cardiovascular responses, and the other monitors the Spacelab environment to determine the growth of fungi and bacteria over the course of the mission.



After ingesting salt tablets and water, crewmembers are exposed to negative pressure in the LBNP device. This treatment reduces cardiovascular deconditioning upon return to Earth.

Lower Body Negative Pressure: Countermeasure Investigation for Reducing Postflight Orthostatic Intolerance

Principal Investigator:
Dr. J. Charles

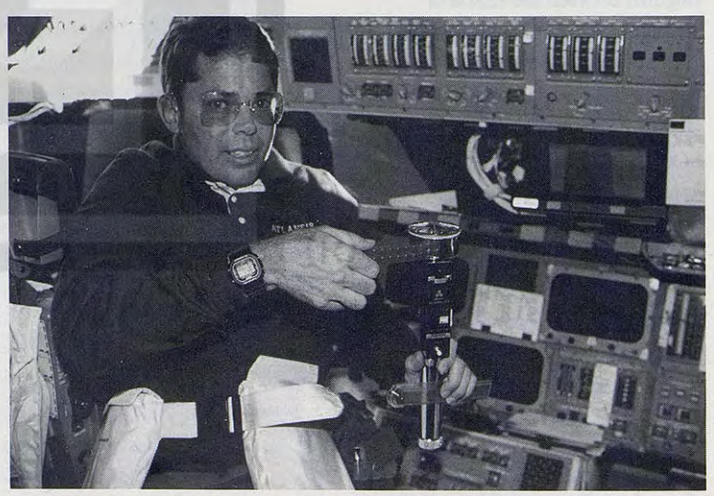
Without the force of gravity, fluids shift toward astronauts' heads and upper torsos. This fluid shift, which makes astronauts' faces appear puffy, is associated with many other physiological changes, including fluid volume loss and altered control of cardiovascular function. While these are natural adaptations to weightlessness, they may present problems when the crew returns to Earth's 1-g environment. Because of these changes, astronauts returning to Earth's gravity may experience reduced blood flow to the brain when they stand up; in extreme cases, this could cause loss of consciousness. Previous flight investigations indicate that this negative response may be countered by ingesting salt tablets and a liter of water while exposing the lower body to reduced atmospheric pressure (lower body negative pressure or LBNP). This combined treatment has been shown to recondition the cardiovascular system for up to 24 hours.

For the 4-hour treatment, called a "soak," a 4-foot, cylindrical, fabric-covered framework sack (the LBNP device) seals just below the astronaut's waist, and air is removed to create a negative pressure. While in the device, the crewmember ingests water and salt tablets. Scientists will evaluate the success of the treatment by examining physiological data taken after landing. The LBNP device will be used to monitor the adaptation to spaceflight by performing brief LBNP tests every few days in flight. During each test, measurements will be made of heart size and function by ultrasound cardiology, blood pressure, and pulse rate.

Microbial Air Sampler

Principal Investigator:
Dr. D.L. Pierson

Because certain microorganisms can evoke allergic reactions or infections, maintaining acceptable air quality in "tight buildings," i.e., those with little or no outdoor air, is important to protect the health of people who inhabit those buildings. Spacecraft may be viewed as the ultimate tight building because the air supply is completely contained within the vehicle. In addition, the absence of gravity results in the formation of bioaerosols, because particles that normally settle onto surfaces on Earth remain airborne in space. Measurements of air quality taken before and after brief Shuttle missions suggest that inflight microbial populations are typical of those from

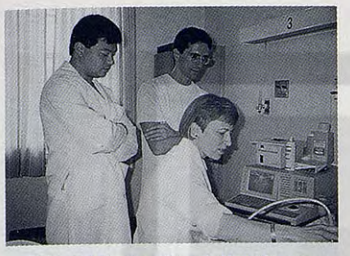


The MAS is used to collect microbes inside the Spacelab.

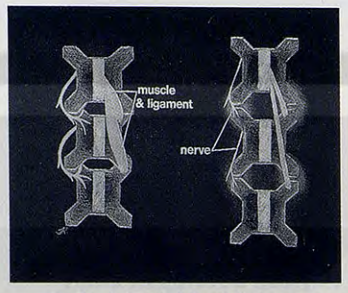
IML-2 Missi Chiao and Don ultrasound sc during

crowded indoo closed environ however, the n bacteria gradu flight, which is that the Shutt tem was not d borne microorg

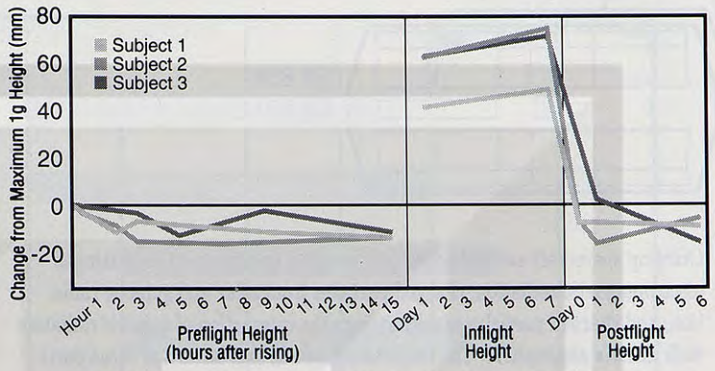
This exper held, battery-p sampler to coll borne bacteria IML-2 mission lected from th deck, and the times through characterize a Ambient air is pler, and parti lected on plast microbiologica samples are c and then the removed and fungal contam fied after retu cedure allows of airborne mi identified ove Shuttle missi levels of micr then recomme to counter the tional air-filtr



IML-2 Mission Specialists Leroy Chiao and Donald Thomas observe an ultrasound scanning demonstration during crew training.



As the intervertebral distance increases in microgravity, the muscles, ligaments, and/or nerves are stretched and can cause pain.



The IML-1 height data confirmed the lengthening and straightening of the spine during spaceflight.

crowded indoor environments. In the closed environment of the Shuttle, however, the number of airborne bacteria gradually increases during flight, which is not unexpected given that the Shuttle's air-handling system was not designed to remove airborne microorganisms.

This experiment uses a handheld, battery-powered centrifugal air sampler to collect samples of airborne bacteria and fungi during the IML-2 mission. Samples will be collected from the Spacelab, the flight deck, and the middeck at various times throughout the mission to characterize air quality over time. Ambient air is pulled into the sampler, and particles in the air are collected on plastic strips containing microbiological culture media. Air samples are collected for 2 minutes, and then the culture-medium strip is removed and stowed. Bacterial and fungal contaminants will be identified after return to Earth. This procedure allows the number and type of airborne microorganisms to be identified over a relatively long Shuttle mission. If it is shown that levels of microorganisms increase, then recommendations will be made to counter these effects with additional air-filtration devices.

Spinal Changes in Microgravity (SCM)
Payload Developer: CSA

Physiological measurement equipment has been developed to allow coordinated measurements of changes that occur during spaceflight in the spine, spinal cord function, and several related physiological systems. The specialized equipment includes nerve stimulation and recording, ultrasound imaging, cardiovascular function recording, and stereophotography. For the first time, this experiment hardware will allow a unified approach to examination of the spine and autonomic nervous system during spaceflight.

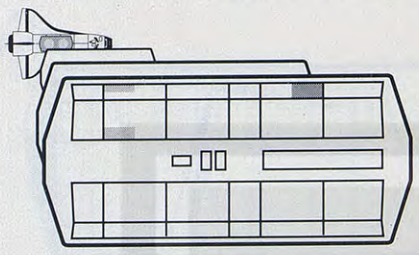
Spinal Changes in Microgravity
Principal Investigator: Dr. J.R. Ledsome

In space, there is a height increase as the human vertebral column lengthens and straightens, probably because gravity does not compress the body. On past U.S. spaceflights, more than two-thirds of astronauts reported back pain. This back pain may be associated with the increase in height. On IML-1, members of the SCM team performed the first systematic measurements of changes in height and spinal contour. The astronauts increased in height from 4.8 to 7.4 mm above their greatest (early morning) height on Earth, and there was flattening of the normal spinal contour. On IML-2, measurements will be made to determine whether the lengthening of the spinal column is associated with any changes in the function of the spinal cord or the spinal nerve roots, the nerves that branch off the spinal cord. These data will be useful in understanding the causes of back pain in astronauts. The information on spinal cord function is necessary to ensure the well-being of astronauts on prolonged spaceflights. There may also be implications for people who experience spinal cord traction on Earth.

Astronauts will complete a daily questionnaire describing any back pain and associated symptoms of spinal cord dysfunction, such as numbness. Subjects will measure their height daily and, during three sessions, take self stereophotographs in seven different positions designed to provide information about changes in spinal contour, height, and the range of motion of the vertebral column. These changes may reflect tension on the spinal cord and nerve roots.

A nerve stimulation and recording device will be used to measure the time it takes for a sensory impulse to travel from the foot to the brain. Variation in heart rate during controlled respiration, changes in blood pressure with isometric exercise, and completeness of bladder emptying will be measured noninvasively to determine the status of the autonomic nervous system. Ultrasound imaging will be used to measure the distance between the bones of the spinal column to determine if the overall height increase is caused by an increase in the thickness of the intervertebral discs. These tests will be conducted three times during the flight. They will also be conducted pre- and postflight, along with magnetic resonance imaging of the spine and clinical back examination. ●

RADIATION BIOLOGY

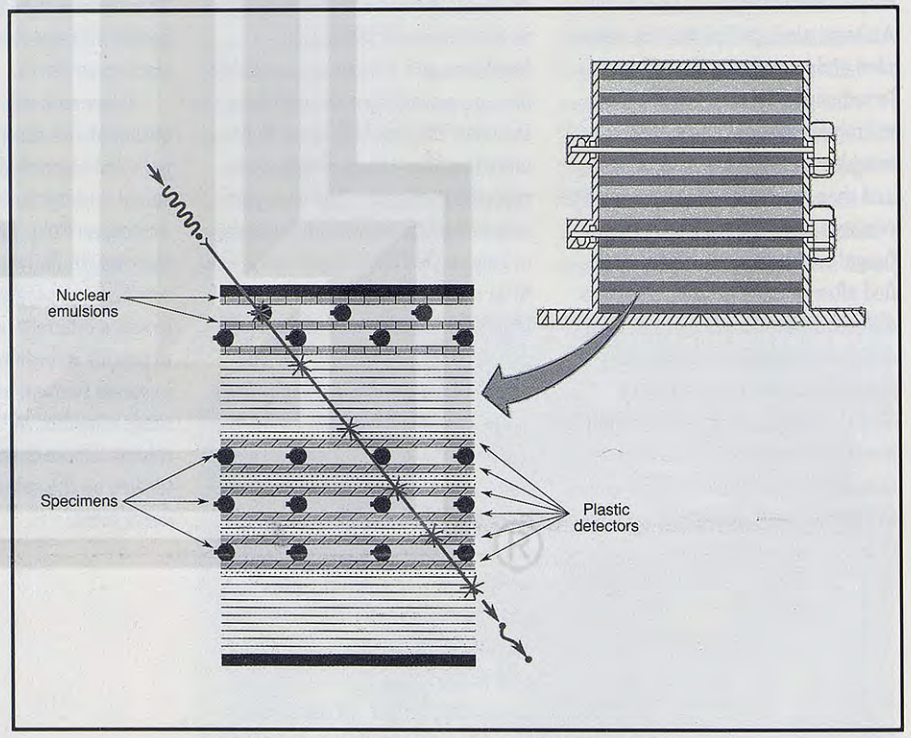


Orbiting spacecraft are embedded in a complex environment consisting of electromagnetic radiation, charged particles from solar and galactic radiation, and charged particles resulting from the interaction of galactic radiation with Earth's atmosphere. The importance, effect, and hazard of these particles must be better understood, as previous experiments have shown that particles of high atomic number and high energy (HZE particles) have potentially serious biological effects on living organisms. Earth-bound experiments cannot fully investigate the hazardous effects of HZE particles because the atmosphere shields most of their effects. Two complementary IML-2 investigations, along with radiation experiments in Biorack (*see page 26*), use different types of detectors to measure this radiation and its effects on living organisms. These data are especially important to help in the development of space radiation forecasting systems that may be needed for longer spaceflights.

Biostack (BSK)

Payload Developer: DLR
Principal Investigator: Dr. G. Reitz

Biostack will employ radiation detectors to monitor incoming particles during IML-2. Within sealed aluminum containers, biological specimens are arranged in fixed positions between nuclear track detectors. This allows scientists to localize the trajectory of each heavy ion in the biological layer and to identify the site of penetration inside the biological subject. The precision for reconstructing the geometric relation between the particle trajectory and the organism can be as low as 0.2 microns for the smallest objects, bacterial spores. The experiment uses a wide spectrum of biological specimens, such as spores, yeast cells, shrimp eggs, and plant seeds. These species have different levels of biological organization and radiation sensitivity. The species are well-known and have shown at least one typical genetic or somatic radiation effect. The specimens will be studied postflight to identify any changes in cellular and organic development, damage to nuclei and other subcellular organs, and induction of mutations leading to somatic or genetic changes of biological significance. Information will also be obtained on the spectrum of charge and energy level of cosmic radiation inside Spacelab.



When cosmic particles pass through the Biostack, they deposit their high energies in layers of radiation detectors and live specimens.

RRMD

Real-Tim Monitorin (RRMD)

Payload De
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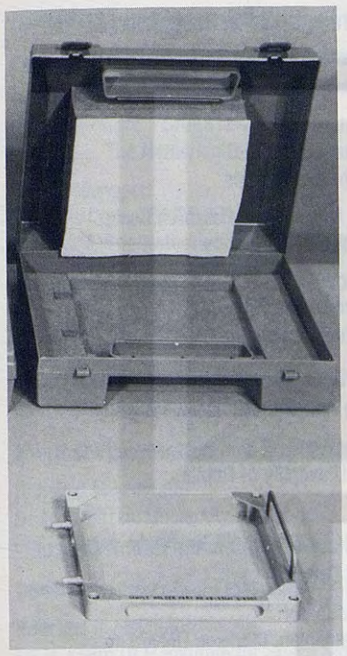
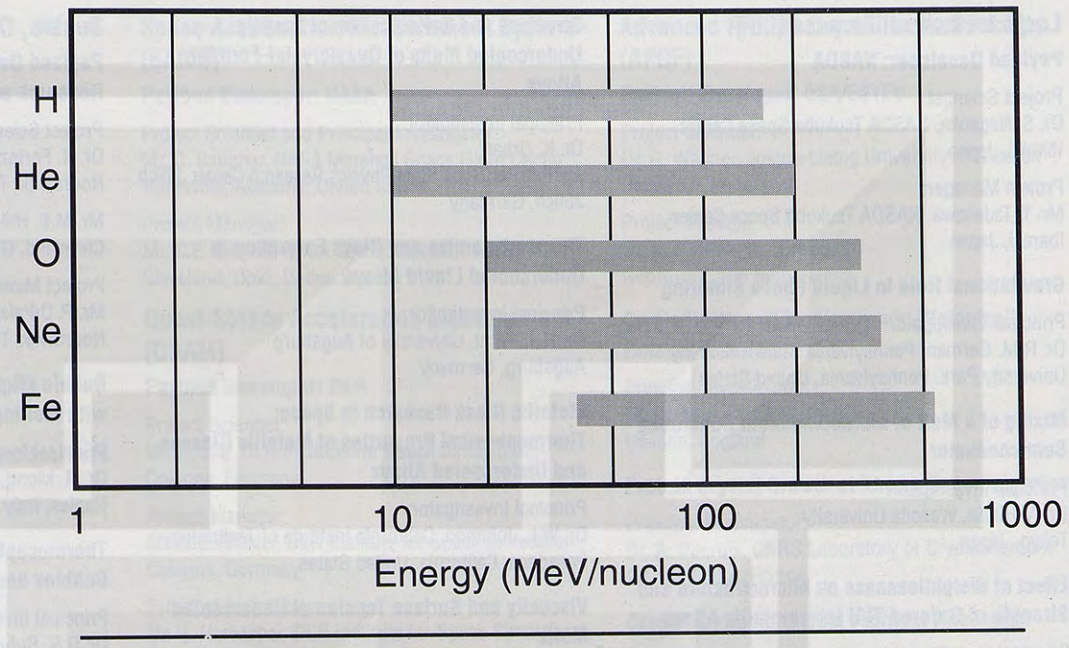


RRMD sample holder



This chart shows incident particles that the RRMD will identify and the energy ranges the device can detect.

Real-Time Radiation Monitoring Device (RRMD)

Payload Developer: NASDA
Principal Investigator: Dr. T. Doke

This IML-2 device is the first one ever flown that actively measures the high-energy cosmic radiation entering Spacelab on orbit. It rapidly collects data necessary to analyze the influences of radiation on the crew, the payload, and biological specimens. During the flight, each time a cosmic ray particle enters Spacelab, a spectroscope sensor measures the element energy and incident direction of each cosmic ray particle; these parameters determine the strength of the radiation. An electronics control unit records signals from the detector and transmits them to the ground during the mission. As a basis for a space weather-forecasting network that might be established for future spacecraft, data will also be transmitted to remote centers and compared with other observed radiation information, such as optical and X-ray observations. Bacteria with a high radiation sensitivity are sandwiched between solid-state nuclear track detectors in a container on top of the spectrometer; postflight, scientists can measure radiation damage to the bacteria cells and study their ability to recover and repair themselves after a cosmic ray impact. IML-2 data will be compared to passive track dosimeters attached with biological specimens on top of the active detectors and also with Biostack detectors, which have flown on several previous missions, including IML-1. ●

Key Personnel

Materials Science

Large Isothermal Furnace (LIF)

Payload Developer: NASDA

Project Scientist:
Dr. S. Nagaoka, NASDA Tsukuba Space Center
Ibaraki, Japan

Project Manager:
Mr. T. Tadakawa, NASDA Tsukuba Space Center
Ibaraki, Japan

Gravitational Role in Liquid Phase Sintering

Principal Investigator:
Dr. R.M. German, Pennsylvania State University
University Park, Pennsylvania, United States

Mixing of a Melt of Multicomponent Compound Semiconductor

Principal Investigator:
Dr. A. Hirata, Waseda University
Tokyo, Japan

Effect of Weightlessness on Microstructure and Strength of Ordered TiAl Intermetallic Alloys

Principal Investigator:
Dr. M. Takeyama, National Research Institute of Metals
Tokyo, Japan

Electromagnetic Containerless Processing Facility (TEMPUS)

Payload Developer: DARA

Project Scientists:
Dr. I. Egry
DLR Institute for Space Simulation
Cologne, Germany

Dr. M. Robinson
NASA Marshall Space Flight Center
Huntsville, Alabama, United States

Project Manager:
Mr. W. Dreier, DARA
Bonn, Germany

Effects of Nucleation by Containerless Processing in Low Gravity

Principal Investigator:
Dr. R.J. Bayuzick, Vanderbilt University
Nashville, Tennessee, United States

Alloy Undercooling Experiments

Principal Investigator:
Dr. M.C. Flemings
Massachusetts Institute of Technology
Cambridge, Massachusetts, United States

Non-Equilibrium Solidification of Largely Undercooled Melts

Principal Investigator:
Dr. D.M. Herlach, DLR Institute for Space Simulation
Cologne, Germany

Structure and Solidification of Largely Undercooled Melts of Quasicrystal-Forming Alloys

Principal Investigator:
Dr. K. Urban
Institute for Solid State Physics Research Center Jülich
Jülich, Germany

Thermodynamics and Glass Formation in Undercooled Liquid Alloys

Principal Investigator:
Dr. H.J. Fecht, University of Augsburg
Augsburg, Germany

Metallic Glass Research in Space: Thermophysical Properties of Metallic Glasses and Undercooled Alloys

Principal Investigator:
Dr. W.L. Johnson, California Institute of Technology
Pasadena, California, United States

Viscosity and Surface Tension of Undercooled Melts

Principal Investigator:
Dr. I. Egry, DLR Institute for Space Simulation
Cologne, Germany

Measurement of the Viscosity and Surface Tension of Undercooled Melts under Microgravity Conditions and Supporting MHD Calculations

Principal Investigator:
Dr. J. Szekely, Massachusetts Institute of Technology
Cambridge, Massachusetts, United States

Fluid Science

Bubble, Drop, and Particle Unit (BDPU)

Payload Developer: ESA/European Space Research and Technology Center (ESTEC)

Project Scientists:
Dr. R. Fortezza, ESA/ESTEC
Noordwijk, The Netherlands

Mr. M.E. Hill, NASA Lewis Research Center
Cleveland, Ohio, United States

Project Manager:
Mr. P. DiPalermo, ESA/ESTEC
Noordwijk, The Netherlands

Bubble Migration, Coalescence, and Interaction with Melting and Solidification Fronts

Principal Investigator:
Dr. R. Monti, University of Nobile
Naples, Italy

Thermocapillary Migration and Interactions of Bubbles and Drops

Principal Investigator:
Dr. R.S. Subramanian, Clarkson University
Potsdam, New York, United States

Bubble Behavior under Low Gravity

Principal Investigator:
Dr. A. Viviani, MARS Center
Naples, Italy

Interfacial Phenomena in a Multilayered Fluid System

Principal Investigator:
Dr. J.N. Koster, University of Colorado
Boulder, Colorado, United States

Thermocapillary Instability in a Three-Layer System

Principal Investigator:
Dr. J.C. Legros, Free University of Brussels
Brussels, Belgium

Nucleation, Bubble Growth, Interfacial Micro-Layer, Evaporation and Condensation Kinetics

Principal Investigator:
Dr. J. Straub, Technical University of Munich
Munich, Germany

Static and Dynamic Behavior of Liquid in Corners, Edges, and Containers

Principal Investigator:
Dr. D. Langbein, Battelle Europe
Frankfurt, Germany

Critical Point Facility (CPF)

Payload Developer: ESA/ESTEC

Project Scientist:
Dr. T. Dewandre, ESA/ESTEC
Noordwijk, The Netherlands

Project Manager:
Mr. M.F., Cork, ESA/ESTEC
Noordwijk, The Netherlands

The Piston Effect

Principal Investigator:
Dr. D. Beysens
CEA Department of Condensed Matter Physics
Gif sur Yvette, France

Thermal Equilibration in a One-Component Fluid

Principal Investigator:
Dr. R.A. Ferrell, University of Maryland
College Park, Maryland, United States

Density Equilibration Time Scale

Principal Investigator:
Dr. H. Klein, DLR Institute for Space Simulation
Cologne, Germany

Heat Transport and Density Fluctuations in a Critical Fluid

Principal Investigator:
Dr. A.C. Michels, University of Amsterdam
Amsterdam, The Netherlands

Microgravity Environment and Countermeasures

Space Acceleration Measurement System (SAMS)

Payload Developer: NASA

Project Scientist and Principal Investigator:
Mr. C. Baugher, NASA Marshall Space Flight Center
Huntsville, Alabama, United States

Project Manager:
Mr. C.E. Siegert, NASA Lewis Research Center
Cleveland, Ohio, United States

Quasi-Steady Acceleration Measurement (QSAM)

Payload Developer: DLR

Project Scientist:
Mr. R. Jilg, DLR Institute for Space Simulation
Cologne, Germany

Project Manager:
Mr. H.E. Richter, DLR Institute for Space Simulation
Cologne, Germany

Principal Investigator:
Dr. H. Hamacher, DLR Institute for Space Simulation
Cologne, Germany

Vibration Isolation Box Experiment System (VIBES)

Payload Developer: NASDA

Project Scientist:
Dr. S. Nagaoka, NASDA Tsukuba Space Center
Ibaraki, Japan

Project Manager:
Mr. T. Tadakawa, NASDA Tsukuba Space Center
Ibaraki, Japan

Influence of G-Jitter on Natural Convection and Diffusive Transport

Principal Investigator:
Dr. H. Azuma, National Aerospace Laboratory
Chohu-shi, Japan

Study on Thermally Driven Flow under Microgravity

Principal Investigator:
Dr. M. Furukawa, NASDA Tsukuba Space Center
Ibaraki, Japan

Bioprocessing

Advanced Protein Crystallization Facility (APCF)

Payload Developer: ESA/ESTEC

Project Scientist:
Dr. G. Wagner, Justus-Liebig University of Giessen
Giessen, Germany

Project Manager:
Dr. K. Fuhrmann, ESA/ESTEC
Noordwijk, The Netherlands

Crystallization of Medically and Biologically Related Proteins

Principal Investigator:
Dr. D. Blow, Imperial College
London, England

Protein Crystal Growth at Known Supersaturation

Principal Investigator:
Dr. A. Ducruix, CNRS Laboratory of Crystallography
Gif sur Yvette, France

Crystallization of Visual Pigment Rhodopsin

Principal Investigator:
Dr. W. J. de Grip, University of Nijmegen
Nijmegen, The Netherlands

Crystallization of Ribosomal 5S RNA

Principal Investigator:
Dr. V.A. Erdmann, Free University of Berlin
Berlin, Germany

Crystallization of tRNA

Principal Investigator:
Dr. R. Giegé
CNRS Institute of Molecular and Cellular Biology
Strasbourg, France

Crystallization of Lysozyme

Principal Investigator:
Dr. J. Helliwell, University of Manchester
Manchester, England

Microgravity Effects on Macromolecule and Virus Crystallization

Principal Investigator:
Dr. A. McPherson, University of California at Riverside
Riverside, California, United States

Crystal Packing Interactions Between Different Crystal Forms of Macromolecules Grown on Earth and in Microgravity

Principal Investigator:
Dr. L. Sjolin, Chalmers University of Technology
Göteborg, Sweden

Key Personnel

Bioprocessing

Crystallization of Intact Ribosomal Particles under Microgravity

Principal Investigator: Dr. A. Yonath
Max-Planck-Laboratory for Ribosomal Structure
Hamburg, Germany

Crystallization of the Small Receptor Molecules Archaebacterial Rhodopsin and Plant Calmodulin

Principal Investigator:
Dr. G. Wagner, Justus-Liebig University of Giessen
Giessen, Germany

Free-Flow Electrophoresis Unit (FFEU)

Payload Developer: NASDA

Project Scientist:
Dr. S. Nagaoka, NASDA Tsukuba Space Center
Ibaraki, Japan

Project Manager:
Mr. T. Tadakawa, NASDA Tsukuba Space Center
Ibaraki, Japan

Gravitational Role in Electrophoretic Separations of Pituitary Cells and Granules

Principal Investigator:
Dr. W.C. Hymer, Pennsylvania State University
University Park, Pennsylvania, United States

Separation of Chromosome DNA of a Nematode, *C. elegans*, by Electrophoresis

Principal Investigator:
Dr. H. Kobayashi, Josai University
Saitama, Japan

Experiments Separating the Culture Solution of Animal Cells in High Concentration under Microgravity

Principal Investigator:
Mr. T. Okusawa, Hitachi, Ltd.
Ibaraki, Japan

Applied Research on Separation Methods Using Space Electrophoresis (RAMSES)

Payload Developer: CNES

Project Scientist:
Dr. F. Jamin-Changeart, CNES
Toulouse, France

Project Manager:
Mr. F. Faure, Matra-Marconi Space
Toulouse, France

Optimization of Protein Separation

Principal Investigator: Dr. V. Sanchez
CNRS Chemical Engineering Laboratory
Toulouse, France

Electrohydrodynamic Sample Distortion

Principal Investigator:
Dr. R. Snyder, NASA Marshall Space Flight Center
Huntsville, Alabama, United States

Space Biology

Aquatic Animal Experiment Unit (AAEU)

Payload Developer: NASDA

Project Scientist:
Dr. S. Nagaoka, NASDA Tsukuba Space Center
Ibaraki, Japan

Project Manager:
Mr. T. Tadakawa, NASDA Tsukuba Space Center
Ibaraki, Japan

Mechanism of Vestibular Adaptation of Fish under Microgravity

Principal Investigator:
Dr. A. Takabayashi, Fujita-Gakuen Health University
Tokyo, Japan

Early Development of a Gravity-Receptor Organ in Microgravity

Principal Investigator:
Dr. M.L. Wiederhold
University of Texas Health Science Center
San Antonio, Texas, United States

Fertilization and Embryonic Development of Japanese Newts in Space

Principal Investigator:
Dr. M. Yamashita
Institute for Space and Astronautical Science
Kanagawa, Japan

Mating Behavior of the Fish (Medaka) and Development of their Eggs in Space

Principal Investigator:
Dr. K. Ijiri, University of Tokyo
Tokyo, Japan

Biorack (BR)

Payload Developer: ESA/ESTEC

Project Scientist:
Dr. E. Brinckmann, ESA/ESTEC
Noordwijk, The Netherlands

Project Manager:
Mr. P. Genzel, ESA/ESTEC
Noordwijk, The Netherlands

Antigen Presentation and T-Cell Proliferation in Micro-G (Antigen)

Principal Investigator:
Dr. A. Cogoli, University of Sassari, Sassari, Italy
and
Space Biology Group of ETH, Zurich, Switzerland

Lymphocyte Activation, Differentiation, and Adhesion Dependence on Activation (Adhesion)

Principal Investigator:
Dr. A. Cogoli, University of Sassari, Sassari, Italy
and
Space Biology Group of ETH, Zurich, Switzerland

Lymphocyte Movements and Interactions (Motion)

Principal Investigator:
Dr. A. Cogoli
University of Sassari, Sassari, Italy
and
Space Biology Group of ETH, Zurich, Switzerland

Effect of Microgravity on Cellular Activation: The Role of Cytokines (Cytokines)

Principal Investigator:
Dr. D. Schmitt, Laboratory of Immunology
Toulouse, France

Effect of Microgravity on Cellular Activation: The Role of Cytokines (Phorbol)

Principal Investigator:
Dr. D. Schmitt, Laboratory of Immunology
Toulouse, France

Cell Microenvironment and Membrane Signal Transduction in Microgravity (Signal)

Principal Investigator:
Dr. P. Bouloc, CNRS Jacques Monod Institute
Paris, France

Effect of Stirring and Mixing in a Bioreactor Experiment in Microgravity (Bioreactor)

Principal Investigator:
Dr. A. Cogoli, Space Biology Group of ETH
Zurich, Switzerland

Molecular Biological Investigations of Animal Multi-Cell-Aggregates Reconstituted under Microgravity (Aggregate)

Principal Investigator:
Dr. U.A.O. Heinlein, Heinrich-Heine-University
Düsseldorf, Germany

Regulation of Cell Growth and Differentiation by Microgravity: Retinoic Acid-Induced Cell Differentiation (Mouse)

Principal Investigator:
Dr. S.W. de Laat
Netherlands Institute for Developmental Biology
Utrecht, The Netherlands

The Sea Urchin Larva, a Potential Model for Studying Biomineralization and Demineralization Processes in Space (Urchin)

Principal Investigator:
Dr. H.J. Marthy, CNRS Observatoire Océanologique
Banyuls sur Mer, France

The Effects of Microgravity and Varying 1-g Exposure Periods on Bone Resorption; an *In Vitro* Experiment (Bones)

Principal Investigator:
Dr. J.P. Veldhuijzen
Amsterdam Academic Center for Dentistry
Amsterdam, The Netherlands

Investigation of the Mechanisms Involved in the Effects of Space Microgravity on *Drosophila* Development, Behavior and Aging (Drosophila)

Principal Investigator:
Dr. R. Marco, Independent University of Madrid
Madrid, Spain

The Role of Gravity in the Establishment of Embryonic Axes in the Amphibian Embryo (Eggs)

Principal Investigator:
Dr. G.A. Ubbels
The Netherlands Institute for Developmental Biology
The Hubrecht Laboratory
Utrecht, The Netherlands

Effect of Microgravity on Lentil Morphogenesis (Lentil)

Principal Investigator:
Dr. G.E. Perbal, Pierre and Marie Curie University
Paris, France

Root Orientation, Growth Regulation, Adaptation, and Agravitropic Behavior of Genetically Transformed Roots (Transform)

Principal Investigator:
Dr. T.H. Iversen, University of Trondheim
Dragvoll, Norway

Plant Growth and Random Walk (Random)

Principal Investigator:
Dr. A. Johnsson, University of Trondheim
Dragvoll, Norway

Dosimetric Mapping inside Biorack on IML-2 (Dosimetry)

Principal Investigator:
Dr. G. Reitz, DLR Institute for Aerospace Medicine
Cologne, Germany

Efficiency of Radiation Repair in Prokaryotes (Repair)

Principal Investigator:
Dr. G. Horneck, DLR Institute for Aerospace Medicine
Cologne, Germany

Radiation Repair Kinetics in Eukaryotes (Kinetics)

Principal Investigator:
Dr. G. Horneck, DLR Institute for Aerospace Medicine
Cologne, Germany

Slow Rotating Centrifuge Microscope (NIZEMI)

Payload Developer: DARA

Project Scientist:
Dr. U. Friedrich, DARA
Bonn, Germany

Project Manager:
Dr. O. Joop, DARA
Bonn, Germany

Gravisensitivity and Geo(gravi)taxis of the Slime Mold *Physarum polycephalum* (Slime Mold)

Principal Investigator:
Dr. I. Block, DLR Institute for Aerospace Medicine
Cologne, Germany

Influence of Accelerations on the Spatial Orientation of the Protozoan *Loxodes striatus* (Loxodes)

Principal Investigator:
Dr. R. Hemmersbach-Krause
DLR Institute for Aerospace Medicine
Cologne, Germany

Graviorientation in *Euglena gracilis* (Euglena)

Principal Investigator:
Dr. D.-P. Häder, Friedrich-Alexander-University
Erlangen, Germany

Effects of Microgravity on *Aurelia* Ephyra Behavior and Development (Jellyfish)

Principal Investigator:
Dr. D. Spangenberg, Eastern Virginia Medical School
Norfolk, Virginia, United States

Gravireaction in *Chara* Rhizoids in Microgravity (Chara)

Principal Investigator:
Dr. A. Sievers
Rheinische Friedrich-Wilhelms-University
Bonn, Germany

Gravisensitivity of Cress Roots (Cress)

Principal Investigator:
Dr. D. Volkmann
Rheinische Friedrich-Wilhelms-University
Bonn, Germany

Lymphocyte Movements and Interactions (Motion)

Principal Investigator:
Dr. A. Cogoli
University of Sassari, Sassari, Italy
and
Space Biology Group of ETH, Zurich, Switzerland

Convective Stability of a Planar Solidification Front (Moni)

Principal Investigator:
Dr. K. Leonartz
Aachen Center for Solidification in Space
(ACCESS e.V.)
Aachen, Germany

Thermoelectric Incubator (TEI) and Cell Culture Kits (CCK)

Payload Developer: NASDA

Project Scientist:
Dr. S. Nagaoka, NASDA Tsukuba Space Center
Ibaraki, Japan

Project Manager:
Mr. T. Tadakawa, NASDA Tsukuba Space Center
Ibaraki, Japan

Gravity and the Stability of the Differentiated State of Plant Embryos

Principal Investigator:
Dr. A.D. Krikorian
State University of New York at Stony Brook
Stony Brook, New York, United States

Effects of Microgravity on the Growth and Differentiation of Cultured Bone-Derived Cells

Principal Investigator:
Dr. Y. Kumei, Tokyo Medical and Dental University
Tokyo, Japan

Differentiation of *Dictyostelium discoideum* in Space

Principal Investigator:
Dr. T. Ohnishi, Nara Medical University
Nara, Japan

Key Personnel

Human Physiology

Extended Duration Orbiter Medical Project (EDOMP)

Payload Developer: NASA

Project Scientist:
Dr. W.T. Norfleet, NASA Johnson Space Center
Houston, Texas, United States

Project Manager:
Mr. J.T. Brown, NASA Johnson Space Center
Houston, Texas, United States

Lower Body Negative Pressure: Countermeasure Investigation for Reducing Postflight Orthostatic Intolerance

Principal Investigator:
Dr. J. Charles, NASA Johnson Space Center
Houston, Texas, United States

Microbial Air Sampler

Principal Investigator:
Dr. D.L. Pierson, NASA Johnson Space Center
Houston, Texas, United States

Spinal Changes in Microgravity (SCM)

Payload Developer: CSA

Project Scientist:
Dr. A. Mortimer, CSA
Ottawa, Ontario, Canada

Project Manager:
Mr. R. Hendry, CSA
Ottawa, Ontario, Canada

Principal Investigator:
Dr. J.R. Ledsome, University of British Columbia
Vancouver, British Columbia, Canada

Radiation Biology

Biostack (BSK)

Payload Developer: DLR

Project Scientist/Manager and Principal Investigator:
Dr. G. Reitz, DLR Institute for Aerospace Medicine
Cologne, Germany

Real-Time Radiation Monitoring Device (RRMD)

Payload Developer: NASDA

Project Scientist:
Dr. S. Nagaoka, NASDA Tsukuba Space Center
Ibaraki, Japan

Project Manager:
Mr. T. Tadakawa, NASDA Tsukuba Space Center
Ibaraki, Japan

Principal Investigator:
Dr. T. Doke, Waseda University
Tokyo, Japan

Mission Management and Development

**NASA Headquarters,
Washington, D.C., United States**

Program Manager: Mr. R.W. Richie
Program Scientist: Dr. B.M. Carpenter

Life Sciences Program Scientist:
Dr. J. Stoklosa

**NASA Marshall Space Flight Center
Huntsville, Alabama, United States**

Mission Manager: Mr. L.R. Upton

Assistant Mission Manager: Mr. M.E. Boudreaux

Mission Scientist: Dr. R.S. Snyder

Assistant Mission Scientist: Ms. T.Y. Miller

Chief Engineer: Mr. W.C. Claunch

Payload Operations Director: Ms. B.J. Cobb

Spacelab Manager: Mr. R.K. McClendon

Training Manager: Ms. A.S. Johnston

Operations Controller: Mr. C.T. Owen

Data Management Coordinator: Mr. L. Bauer

Payload Activity Planner: Mr. C. Traylor

Non-Flight Alternate Payload Specialist:
Ms. J. Sanchez

Safety and Mission Assurance: Mr. C. Cowart

JSC Payload Integration Manager: Mr. F. Moreno

KSC Resident Office: Mr. D. Hunter

KSC Payload Project Engineer: Ms. J. Richards

**Teledyne Brown Engineering Project Office,
Payload Mission Integration Contractor,
Huntsville, Alabama, United States**

Project Manager: Mr. D.S. Copeland

Operations Lead Engineer: Ms. K.H. Brown

Systems Lead Engineer: Mr. W.F. Schneider

Mission-Peculiar Equipment Lead Engineer:
Mr. F.A. Rose

Experiment Integration Engineers:
Mr. M.E. Banks
Ms. L.A. Hanback
Mr. M.W. Phillips
Mr. D. Rary
Mr. J.E. Stanaland
Mr. J.E. Sykes

**McDonnell Douglas,
Spacelab Integration Contractor,
Huntsville, Alabama, United States**

Project Manager: Mr. R.L. Holland

Project Specialist: Ms. G.C. Mitchell

Project Specialist: Mr. T.P. Butler

Software Lead: Ms. J.R. Powell

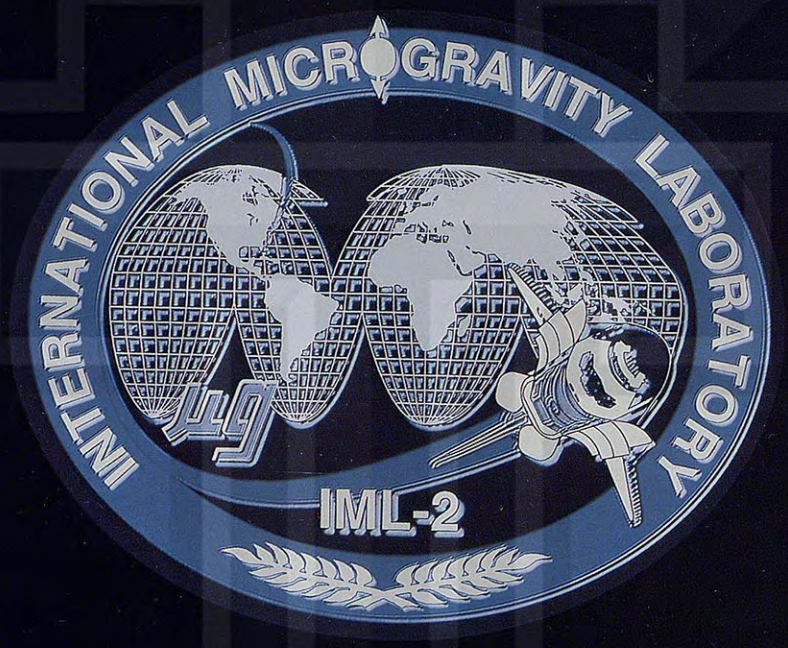
Suggested Terms for Database Searches

Accelerations
Acceleration Signal Modulation
Agravitropic Plant Behavior
Bone Demineralization
Bone Resorption
Bubbles
Cell Activation
Cell Differentiation
Cell Division
Cell Development
Cell Proliferation
Ceramics and Glasses
Containerless Processing
Continuous Flow Electrophoresis
Cosmic Radiation
Critical Point
Crystals
Crystallization
Cytokines
Developmental Biology
Dorsal Light Responses
Dosimetry
Electrohydrodynamic Flow
Electromagnetic Levitation
Electrophoresis
Dialysis Method of Crystal Growth
Fluid Science
Free-Flow Electrophoresis
Free Interface Diffusion
Graviperception
Gravitaxis
Gravity
Gravitational Biology
Gravitropism
Gravity Gradient Attitude
Gravity Threshold
G-Jitter
Hanging Drop Method
Immiscible Fluids
Immune System and Microgravity
Human Physiology
Life Sciences
Liquid-Liquid Diffusion
Lower Body Negative Pressure
Low-Frequency Acceleration
Lymphocytes
Marangoni Convection
Materials Processing in Space/Microgravity/Zero Gravity/Low Gravity
Materials Science
Membrane Signal Transduction
Metal Alloys
Metallic Glasses
Microgravity Science
Microgravity Environment
Neurosensory Science
Nucleation
Orthostatic Intolerance
Otolith
Pharmaceutical Production in Microgravity
Protein Crystals
Quasi-Crystals
Quasi-Steady Acceleration
Radiation
Radiation Biology
Radiation Protection
Residual Acceleration
Second International Microgravity Laboratory (IML-2)
Semiconductors
Sintering
Skylab
Sounding Rockets
Solidification
Solidification Front
Space Applications
Space Adaptation Syndrome (SAS)
Space Biology
Space Biomedicine
Space Bioprocessing
Space Dosimetry
Space Medicine
Space Motion Sickness (SMS)
Space Physiology
Space Spinoffs
Spacelab
Statoliths
Superconductors
Surface Tension
Thermocapillary Fluid Flow
Undercooling
Undercooled Alloys
Vapor Diffusion
Vestibular Function in Space
Viscosity
X-Ray Diffraction

Glossary of Acronyms

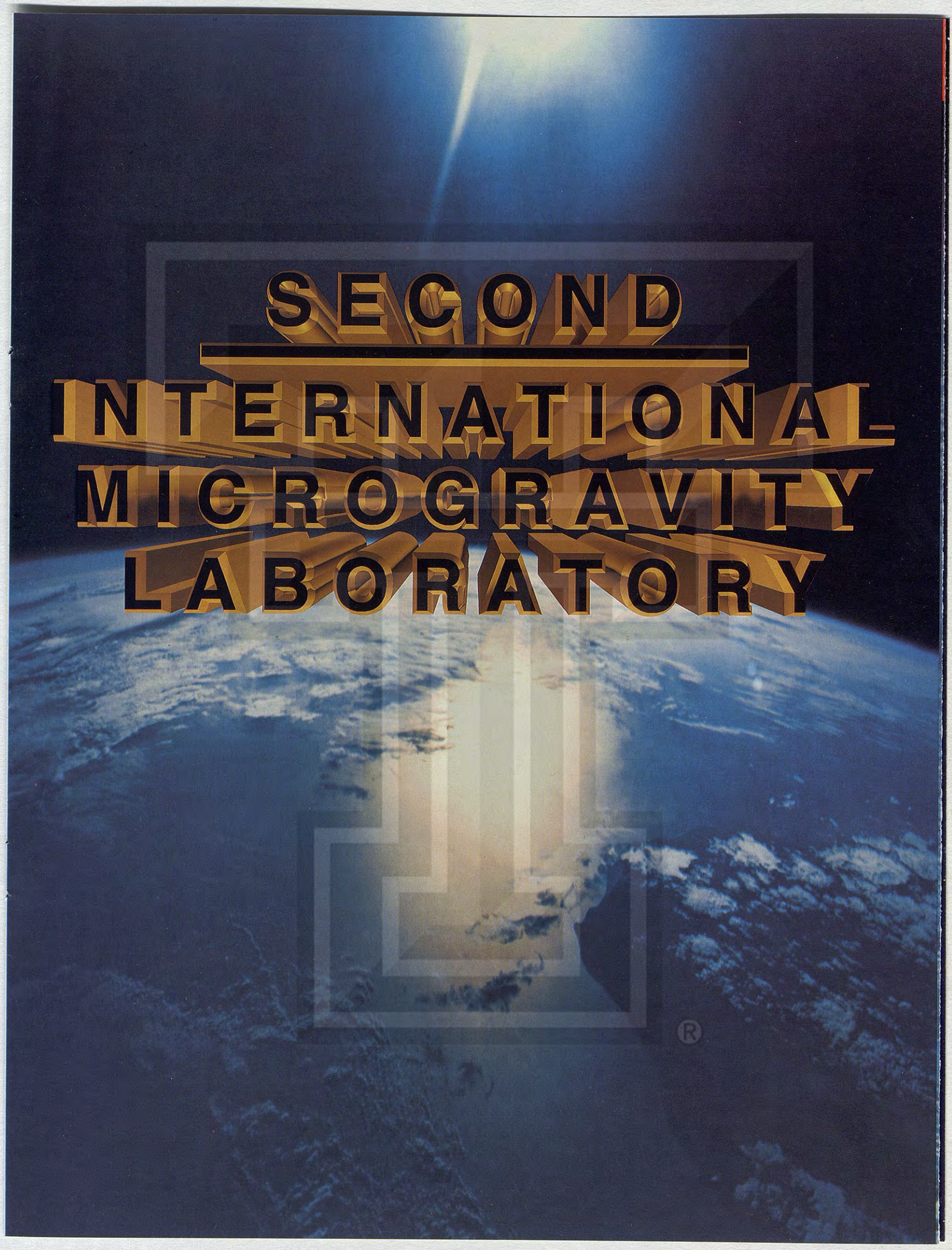
The following acronyms and abbreviations are provided as document and mission references. Those not found in this brochure are provided as assistance in monitoring mission activities.

AAEU	Aquatic Animal Experiment Unit
ABPS	Automated Blood Pressure System
AFD	Aft Flight Deck
AOS	Acquisition of Signal
APCF	Advanced Protein Crystallization Facility
APS	Alternate Payload Specialist
BDPU	Bubble, Drop, and Particle Unit
BR	Biorack
BSK	Biostack
CCK	Cell Culture Kits
CEA	French Atomic Energy Commission/Commissariat à l'Energie Atomique
CI	Co-Investigator
CIC	Crew Interface Coordinator
CNES	French Space Agency/Centre National d'Etudes Spatiales
CNRS	French National Scientific Research Center/Centre National de la Recherche Scientifique
CPF	Critical Point Facility
CSA	Canadian Space Agency/Agence Spatiale Canadienne
DARA	German Space Agency/Deutsche Agentur für Raumfahrtangelegenheiten GmbH
DLR	German Aerospace Research Establishment/Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V.
ECG	Electrocardiograph
EDOMP	Extended Duration Orbiter Medical Project
EKG	Electrocardiogram
ESA	European Space Agency/Agence Spatiale Européenne
ESTEC	European Space Research and Technology Center
FFEU	Free-Flow Electrophoresis Unit
GPWS	General Purpose Work Station
GSFC	Goddard Space Flight Center
HZE	High atomic number and high-energy particles
IML-1	First International Microgravity Laboratory
IML-2	Second International Microgravity Laboratory
IWG	Investigator Working Group
JSC	Johnson Space Center
KSC	Kennedy Space Center
LBNP	Lower Body Negative Pressure
LIF	Large Isothermal Furnace
LOS	Loss of Signal
LSLE	Life Sciences Laboratory Equipment
MAS	Microbial Air Sampler
MCC	Mission Control Center
MD	Middeck
MET	Mission Elapsed Time (time since launch)
MM	Mission Manager
MRI	Magnetic Resonance Imaging
MS	Mission Specialist
MSCI	Mission Scientist
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NIZEMI	Slow Rotating Centrifuge Microscope (Niedergeschwindigkeits-Zentrifugen-Mikroskop)
PCTC	Payload Crew Training Complex
PI	Principal Investigator
POCC	Payload Operations Control Center
POD	Payload Operations Director
PS	Payload Specialist
QSAM	Quasi-Steady Acceleration Measurement
RAMSES	Applied Research on Separation Methods Using Space Electrophoresis/Recherche Appliquée sur les Méthodes de Séparation en Electrophorèse Spatiale
RRMD	Real-Time Radiation Monitoring Device
SAMS	Space Acceleration Measurement System
SAS	Space Adaptation Syndrome
SCM	Spinal Changes in Microgravity
SL	Spacelab
SL-1	Spacelab 1
SL-D1	Spacelab D1
SL-J	Spacelab J
SLS-1	Spacelab Life Sciences 1
SOA	Science Operations Area
STS	Space Transportation System
TEI	Thermoelectric Incubator
TEMPUS	Electromagnetic Containerless Processing Facility/Tiegelfreies Elektromagnetisches Prozesieren unter Schwerelosigkeit
TL	Timeline
USML-1	First United States Microgravity Laboratory
VIBES	Vibration Isolation Box Experiment System



The most beautiful thing we can experience is the mysterious. It is the source of all true art and science. — *Albert Einstein*

NASA

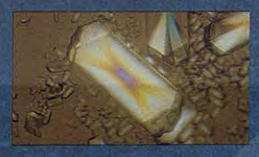

SECOND
INTERNATIONAL
MICROGRAVITY
LABORATORY

INTERNATIONAL MICROG

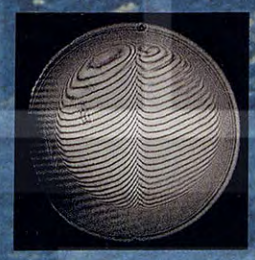
Mission Objective: To conduct microgravity and life sciences investigations that require the unique low-gravity environment created inside an orbiting space laboratory free-falling around Earth.

Many experiments require the microgravity environment that Spacelab provides.

A. Metals and alloys can be positioned using electromagnetic forces and can be processed without containers, which sometimes contaminate samples. This processing technique cannot be used on Earth as effectively as in low-gravity orbit.

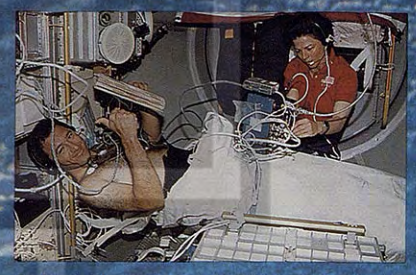


B. Many proteins crystallized in space have formed larger and/or higher quality crystals that reveal information with medical and agricultural applications.



C. Basic fluid properties, such as critical point transitions, are almost impossible to observe on Earth because gravity-driven phenomena disturb or mask the physics being studied.

Scientists can learn more about a variety of living things by studying them away from their 1-g habitat on Earth.



A. Investigators can study how human physiological systems adapt to microgravity and develop treatments to counteract any negative effects.

B. Smaller orga
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An International Alliance

Through 6 international space agencies, more than 200 scientists have developed some 80 investigations for the IML-2 mission.

NASA is the United States agency dedicated to research and development of space science and technology. NASA manages the IML-2 mission, integrates the experiment facilities into a Spacelab payload, and provides transportation for the experiments on the Space Shuttle/Spacelab. The agency is headquartered in Washington, D.C.

ESA sponsors space research and technology among 13 member states (Austria, Belgium, Denmark, France, Germany, Ireland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom), one associate member (Finland), and one country (Canada) under a cooperative agreement. The agency is headquartered in Paris, France.

CSA acts as a focal point for Canada's space activities. The agency encourages and supports research, technology, and operations throughout Canada. CSA is headquartered in Montreal, Quebec, Canada.

ICROGRAVITY LABORATORY

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B. Smaller organisms, such as newts, can develop from embryos and hatch during a mission, allowing scientists to determine if development occurs normally in the space environment.

C. Mammalian cells, bacteria, and whole organisms and plants, such as these cress plants, can be studied to determine how they sense gravity and how it affects their behavior.

Mission Facts

Launch Site	Kennedy Space Center, Florida
Prime Landing Site	Kennedy Space Center, Florida
Flight Number	STS-65
Altitude	160 nautical miles (296 kilometers)
Orbital Path	Circular
Inclination	28.5 degrees
Mission Attitude	Gravity gradient
Mission Duration	14 days nominal
Crew Size	7
Payload	Microgravity and life sciences experiments
Payload Operations	Around the clock

cnes
AGENCE FRANÇAISE DE L'ESPACE

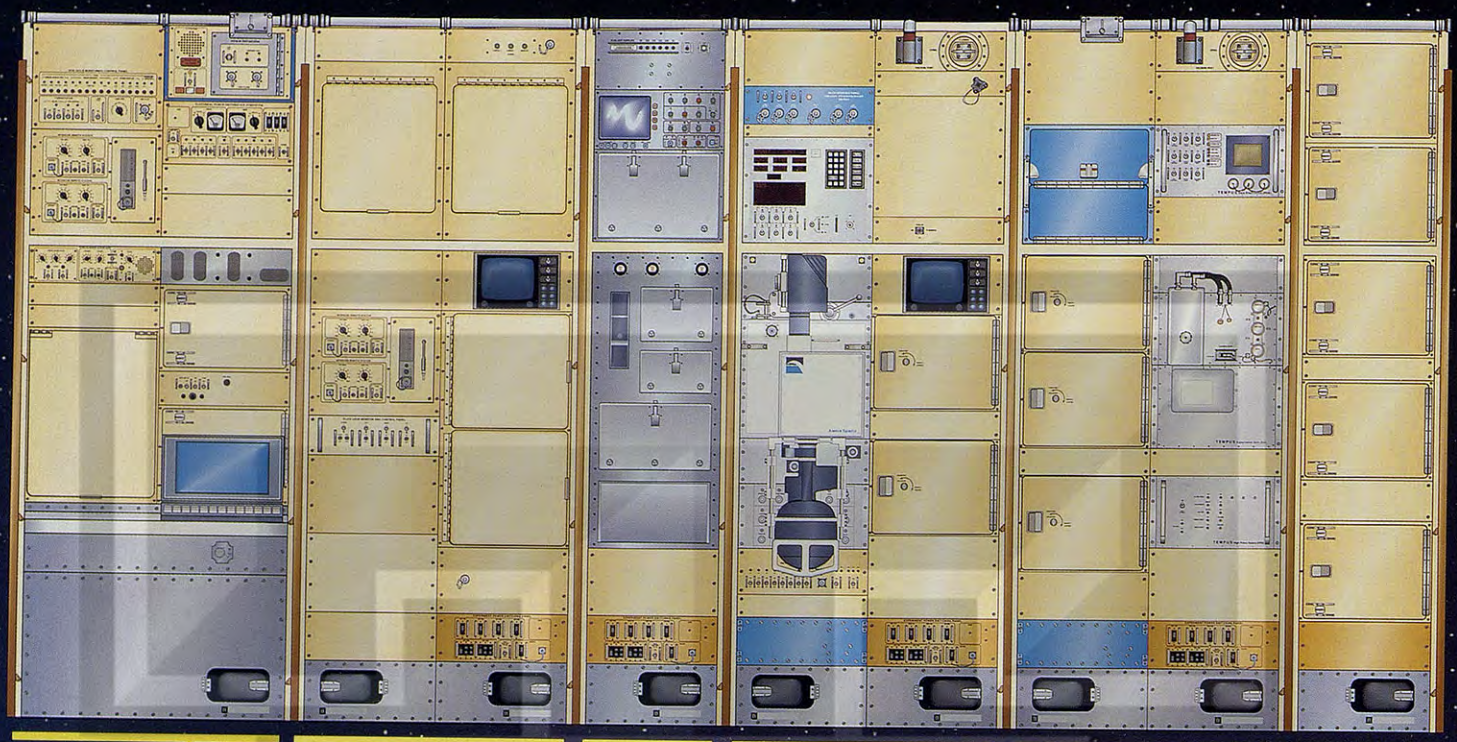
This agency is responsible for developing French space activities. For its program of basic research, it works in conjunction with the scientific community, using the laboratories of the National Scientific Research Center, universities, and other organizations in France. The agency is headquartered in Paris, France.

DARA
DEUTSCHE AGENTUR FÜR RAUMFAHRTANGELEGENHEITEN (DARA) GMBH

DARA is the central organization for planning and managing German space programs. DARA is headquartered in Bonn, Germany. One of DARA's close partners is the German Aerospace Research Establishment, Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V. (DLR), headquartered in Cologne, Germany.

NASDA
宇宙開発事業団

NASDA is responsible for many of Japan's space activities, which include exploring the practical applications of the space environment, conducting microgravity research, and developing satellites. The agency is headquartered in Tokyo, Japan.



Rack 2

Spacelab Control Center: the computer center for managing data and for operating laboratory systems and certain experiments. Some of these activities are carried out by the crew, while others are performed automatically by computers.

Rack 4

Standard Spacelab Subsystems: a water pump that supports experiments; video recorders that support payload data; and an experiment heat exchanger.

Rack 6

Applied Research on Separation Methods Using Space Electrophoresis (RAMSES): electrophoresis separation unit that uses electrical fields to separate biological materials into their individual components and studies the electrophoresis process in low gravity.

Rack 8

Bubble, Drop, and Particle Unit (BDPU): a facility that contains special optical diagnostics, cameras, and sensors for studying fluid behavior in microgravity.

Rack 10

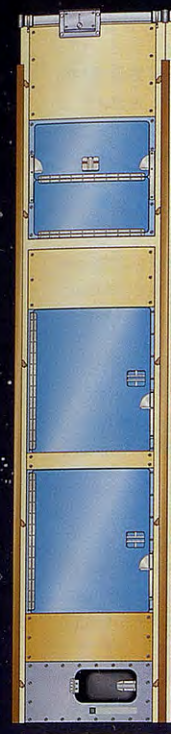
Electromagnetic Containerless Processing Facility (TEMPUS): an electromagnetic device that positions metal alloys so that they do not touch container walls and melts them in an ultra-pure environment; subsequently, data are recorded as the samples solidify.

Rack 12

Experiment Stowage Containers: areas where experiment equipment and samples are stored.

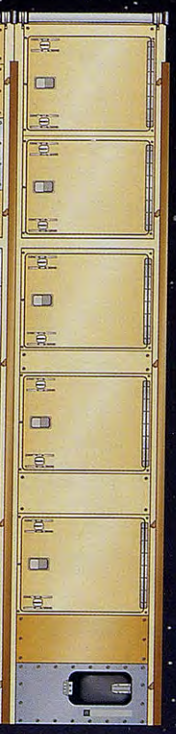
IML-2 CONFIGURATION

The IML-2 mission uses a pressurized Spacelab module containing computers, work areas, instrument racks for experiments, and utilities. Most facilities are mounted in 12 racks in the laboratory module. One experiment facility and other support equipment and samples are located in the middeck, which is connected to Spacelab by a tunnel.



Rack 11

Experiment Stow Containers: areas where experiment equipment and sa ples are stored.



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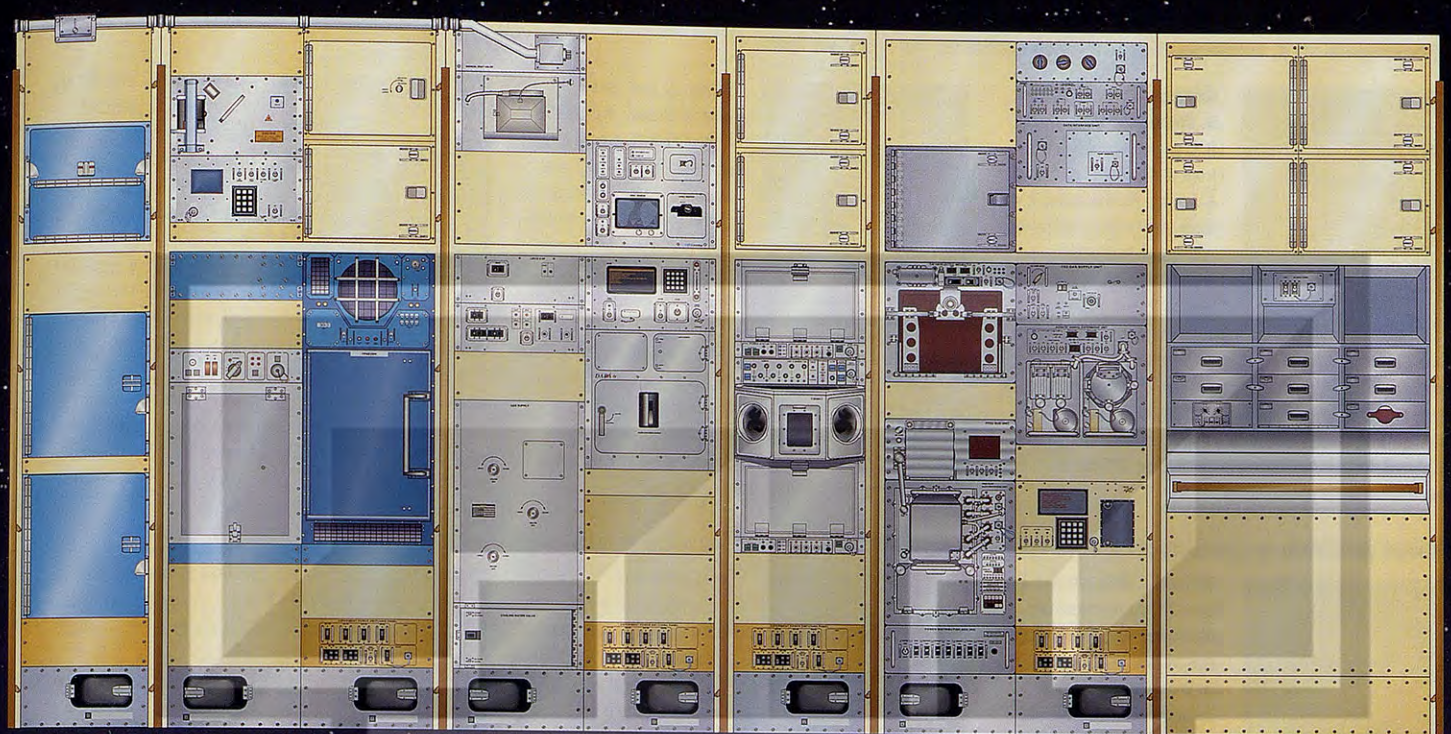


Rack 11

Experiment Stowage Containers: areas where experiment equipment and samples are stored.

Rack 9

Biostack (BSK): sealed detectors that are used to determine the effects of cosmic radiation on biological samples.

Critical Point Facility (CPF): a temperature-controlled facility that supports the investigation of fluids as they undergo critical phase transitions from liquids to gases.

Life Sciences Laboratory Equipment (LSLE) Freezer and Biorack Cooler: facilities that freeze and refrigerate perishable samples to preserve them for postflight analysis.

Rack 7

Large Isothermal Furnace (LIF): a furnace that melts and uniformly mixes compounds and then cools them to produce a solid sample.

Slow Rotating Centrifuge Microscope (NIZEMI): a facility that contains a centrifuge with a microscope and macroscope for observing the movement and behavior of one-celled and multicellular organisms at various gravity levels and monitoring the solidification of materials.

Rack 5

Biorack (BR): a multipurpose facility that supports investigations into the effects of microgravity and cosmic radiation on cells, tissues, plants, bacteria, small animals, and other biological samples. The IML-2 Biorack system contains two incubators and a glovebox.

Rack 3

Vibration Isolation Box Experiment System (VIBES): experiments contained in a box made of special material designed to reduce the effects of accelerations; measures accelerations caused by crew movements and other equipment operations inside Spacelab.

Thermoelectric Incubator (TEI) / Cell Culture Kit (CCK): a general-purpose incubator that provides a temperature- and humidity-controlled environment for cultures of mammal and plant cells.

Free-Flow Electrophoresis Unit (FFEU): an electrophoresis unit that uses an electric field to separate a different set of biological samples than RAMSES.

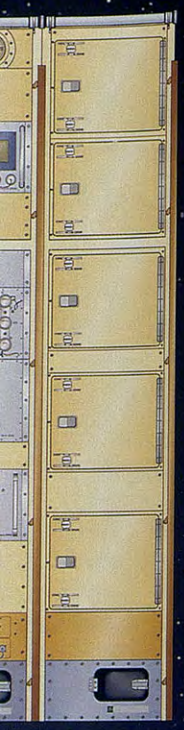
Real-time Radiation Monitoring Device (RRMD): an instrument that actively measures the high-energy cosmic radiation that enters Spacelab on orbit and records the impact of radiation on biological materials.

Aquatic Animal Experiment Unit (AAEU): a facility that provides life support for newts and fish. Investigators will study spawning, fertilization, embryology, and behavior of these animals in microgravity.

Quasi-Steady Acceleration Measurement (QSAM): four rotating and three stationary sensors that measure low-frequency accelerations within Spacelab.

Rack 1

Workbench: an area where crewmembers record data in their logs or carry out general activities. The workbench includes stowage containers, tools, and small equipment.



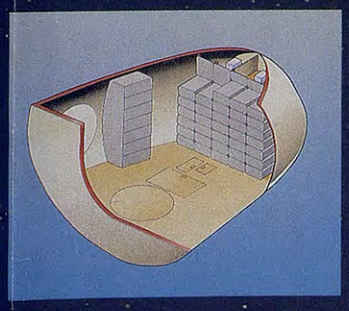
ck 12

periment Stowage ntainers: areas ere experiment uipment and sam- s are stored.

Starboard Side

Middeck

Advanced Protein Crystallization Facility (APCF): a facility that provides a temperature-controlled environment for growing a variety of protein crystals using three different processes and a video-recording device.



Artwork modeled by Chris Scantland using StrataVision 3d and rendered on Silicon Graphics Workstations using Flash Tracer. Retouched and processed by Graphic Systems Retouching, Inc., NYC

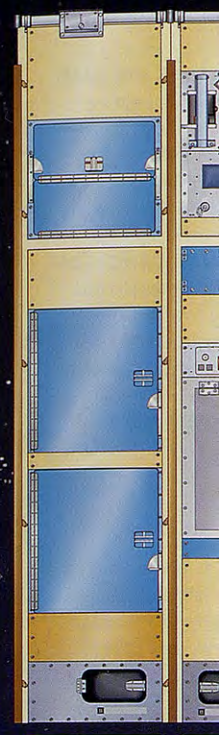
Port Side

Center Aisle (Front to Back)

Space Acceleration Measurement System (SAMS): an electronics package with remote accelerometers placed in three locations in Spacelab to measure accelerations such as those caused by Shuttle maneuvers or crew motion.

Extended Duration Orbiter Medical Project (EDOMP): investigations designed to maintain and evaluate crew health and safety on long-duration Shuttle missions.

Spinal Changes in Microgravity (SCM): cameras that record stereophotographs of the spine and special ultrasound equipment that images vertebral spacing and other data related to spinal and neurosensory system changes induced by microgravity.

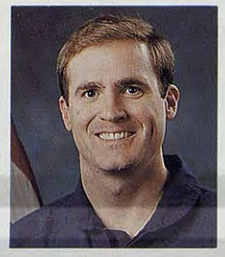


Rack 11

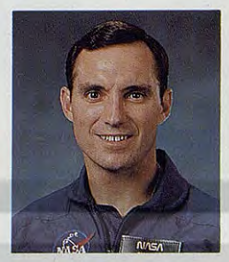
Experiment Stowage Containers: areas where experiment equipment and samples are stored.

The IML-2 crew consists of six NASA astronauts and one payload specialist. The operation of the Space Shuttle is the primary responsibility of the orbiter crew: the commander, the pilot, and a mission specialist, who are all members of the NASA astronaut corps. They also may participate in some experiments conducted by the payload crew, composed of three mission specialists and a payload specialist.

Commander: Col. Robert D. Cabana (USMC) earned a B.S. degree in mathematics from the United States Naval Academy. He completed naval flight officer and pilot training and flew A-6 Intruders with the 1st and 2nd Marine Aircraft Wings. After graduating from the U.S. Naval Test Pilot School, he served as a test pilot at the Naval Air Test Center in the flight systems branch. Col. Cabana was selected to be an astronaut in 1985. He first flew in 1990 on STS-41, during which the *Ulysses* solar exploration spacecraft was deployed. His second flight was in 1992 on STS-53, a Department of Defense mission.



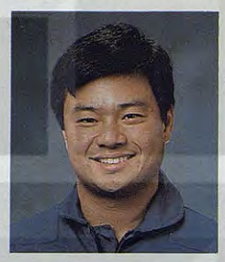
Pilot: Lt. Col. James Donald Halsell, Jr. (USAF) received a B.S. degree in engineering from the United States Air Force Academy and M.S. degrees in management and space operations from Troy University and the Air Force Institute of Technology, respectively. He completed pilot training, graduated from the Air Force Test Pilot School, and performed test flights in the F-4, F-16, and SR-71 aircraft. Lt. Col. Halsell was selected by NASA as an astronaut in 1990. He has served as a spacecraft communicator and as a member of the Astronaut Support Personnel team. IML-2 will be his first spaceflight.



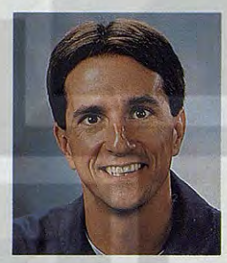
Lt. Col. Carl E. Walz (USAF) received a B.S. degree in physics from Kent State University and an M.S. in solid state physics from John Carroll University. He completed flight test engineer training at the USAF Test Pilot School and later directed a variety of F-16 aircraft and armament development programs at the F-16 Combined Test Force, Edwards Air Force Base. Lt. Col. Walz has logged over 250 flight test hours in the F-16 aircraft. He was selected by NASA as an astronaut in 1990 and was assigned as a mission specialist on STS-51. IML-2 will be his second spaceflight.

Mission specialists are members of the NASA astronaut corps with specialized training in one or more science disciplines.

Richard J. Hieb earned a B.A. in math and physics from Northwest Nazarene College and an M.S. in aerospace engineering from the University of Colorado. He joined NASA in 1979 and was selected as an astronaut in 1985. He first flew in 1991 on STS-39, a Department of Defense mission. His second flight was in 1992 on STS-49, the first flight of *Endeavour*, during which he performed three separate spacewalks that resulted in the successful capture and repair of the stranded Intelsat VI communications satellite. For IML-2, he will serve as payload commander, responsible for Spacelab crew activities.



Leroy Chiao received a B.S. in chemical engineering from the University of California at Berkeley and an M.S. and Ph.D. in chemical engineering from the University of California at Santa Barbara. He has worked on the processing, manufacture, and research of advanced aerospace materials at Hexcel Corporation and the Lawrence Livermore National Laboratory. An instrument-rated pilot, he has logged over 600 flight hours. Dr. Chiao was selected as an astronaut by NASA in 1990 and will serve as a mission specialist on IML-2.



Donald A. Thomas received a B.S. in physics from Case Western Reserve University and an M.S. and Ph.D. in materials science from Cornell University. He has worked on the development of advanced materials and processes for semiconductors at AT&T Bell Laboratories and has worked at the Johnson Space Center on lifetime projections of advanced composite materials. He was principal investigator for the Microgravity Disturbances Experiment that flew on STS-32. An instrument-rated pilot, he has logged over 700 flight hours. Dr. Thomas was selected as an astronaut by NASA in 1990 and will serve as a mission specialist on IML-2.

Payload specialists are scientists who have taken temporary leave from their laboratories to take part in a Shuttle mission. For IML-2, one payload specialist, Dr. Mukai, will be the first Japanese woman to fly aboard the Space Shuttle. The alternate payload specialist, Dr. Favier, a French scientist, will support the mission from the ground control center.

Chiaki Mukai earned an M.D. from Keio University, Tokyo, Japan, and a Ph.D. in physiology from the same institution. She is a board-certified surgeon and has served as the Chief Resident in Cardiovascular Surgery at Keio University Hospital as well as Assistant Professor of Cardiovascular Surgery. Dr. Mukai has been a science astronaut with NASDA since 1985. She served as an alternate payload specialist for the Spacelab J mission, which flew in 1992. Dr. Mukai will serve as a payload specialist on IML-2.

Jean-Jacques Favier received his engineering degree from the National Polytechnical Institute of Grenoble in 1971 and earned a Ph.D. in engineering from the Mining School of Paris and a Ph.D. in metallurgy and physics from the University of Grenoble. Currently, he is Chief of the Materials Science and Processing Service at the French Atomic Energy Commission. Dr. Favier proposed the MEPHISTO program, a collaborative project between the French Space Agency and NASA, and is the principal investigator for a MEPHISTO materials processing experiment that flew on STS-52 and is scheduled for subsequent Space Shuttle flights. He has been a CNES payload specialist candidate since 1985.

MISSION MANAGEMENT

NASA Headquarters is responsible for the IML program, which emphasizes complementary microgravity and life sciences research. NASA's Marshall Space Flight Center (MSFC) is responsible for mission management.

IML-2 Program Manager
Mr. R. Wayne Richie
NASA Headquarters

IML-2 Mission Manager
Mr. Lanny R. Upton
MSFC

IML-2 Program Scientist
Dr. Bradley M. Carpenter
NASA Headquarters

IML-2 Mission Scientist
Dr. Robert S. Snyder
MSFC

National Aeronautics and Space Administration

For more information, contact:

NASA Marshall Space Flight Center
Public Inquiries, Code CA20
Marshall Space Flight Center, Alabama 35812

NASA Headquarters
Public Inquiries, Code POS
Washington, D.C. 20546

MICROGRAVITY SCIENCE & APPLICATIONS

Microgravity (μg) is a term commonly applied to a condition of free-fall within a gravitational field in which the weight of an object is significantly reduced compared to its weight at rest on Earth. When orbiting Earth, a spacecraft is in a condition of continuous free-fall and, thus, is in microgravity.

International Microgravity Laboratory 2

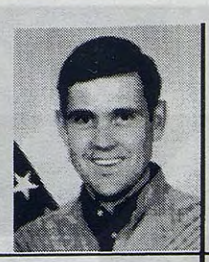
LIFE SCIENCES

FOCUS

STS-65/IML-2

Mission Profile

IML-2 crew

 Commander		 Pilot
Col. Robert D. Cabana		Lt. Col. James Donald Halsell, Jr.
 Mission Specialist	 Payload Commander	 Mission Specialist
Lt. Col. Carl E. Walz	Richard J. Hieb	Dr. Leroy Chiao
 Mission Specialist	 Payload Specialist	 Alternate Payload Specialist in Ground Control Center
Dr. Donald A. Thomas	Dr. Chiaki Mukai	Dr. Jean-Jacques Favier

The Space Shuttle *Columbia*, carrying the IML-2 and a crew of seven, is scheduled for launch from Kennedy Space Center in July 1994. Orbiting the Earth at an altitude of 240 km (160 nmi) at an inclination of 28.5°, *Columbia* will maintain a "gravity gradient" attitude, with its tail aimed at the Earth and its port wing pointing to the line of flight. This attitude minimizes the effect of maneuvering that may introduce artificial gravitational forces and disturb gravity-sensitive experiments. The experiments that are most sensitive to acceleration are positioned near the spacecraft center of gravity—the aft end of the laboratory—where forces created by maneuvering are minimal.

nald Halsell, Jr.

Favier

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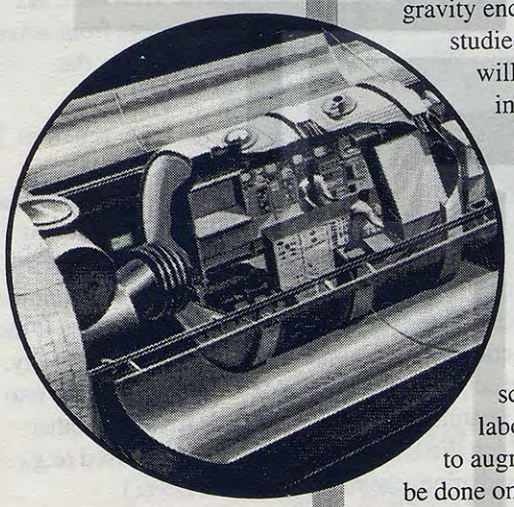
FOCUS

IML-2 Life Sciences

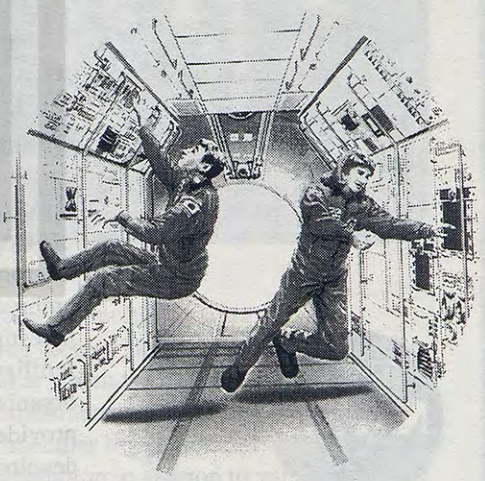
providing answers to fundamental questions

Space is a unique environment in which NASA provides opportunities for life sciences research. The fact that all organisms and biological processes on Earth live and operate under the continual influence of gravity opens a unique window of opportunity for the study of biology in space in the relative absence of gravity. Space experimentation can expand our knowledge about fundamental biological processes, and the information gained is directly applicable to medical problems on Earth. Also, biological research in space enables scientists to understand the changes in human physiology, along with the underlying mechanisms for these changes, which can be expected as a result of exposure to microgravity. This knowledge is critical in building an international space station, establishing a lunar base, and exploring the solar system if these programs are to become realities. Additionally, the reduced gravity encountered in space allows certain characteristics of cells and organisms to be studied using innovative experimental hardware and procedures. These experiments will enhance our understanding of fundamental biological processes for further study in space and on Earth.



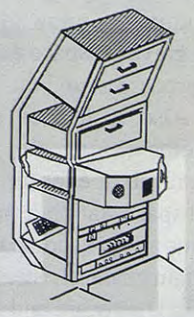
The second International Microgravity Laboratory (IML-2) mission is an international cooperative program that harnesses the scientific talents from countries around the world to conduct microgravity and life sciences experiments in space. In its cargo bay, the Space Shuttle will carry the Spacelab, a functional laboratory for conducting experiments in space. The NASA Life and Biomedical Sciences and Applications Division is responsible for the 49 life sciences investigations (including EDOMP) on the IML-2 mission. These life sciences investigations evolved from experiments conducted in ground-based laboratories and on earlier space flights. In many cases, a prime experimental goal is to augment data from previous missions or to lay the groundwork for investigations to be done on future space flights or in ground-based laboratories.

NASA and the international partners in the space program are supporting three main onboard facilities for conducting multiple experiments: the Biorack, the Niedergerschwindigkeits-Zentrifugen-Kikroskop (NIZEMI) centrifuge, and the Aquatic Animal Experiment Unit (AAEU). Using this and other equipment, scientists from NASA, the European Space Agency (ESA), the Canadian Space Agency (CSA), the National Space Development Agency of Japan (NASDA), the French National Center for Space Studies (CNES), and the German Space Agency (DARA) will conduct a variety of investigations on IML-2. Experiment hardware developed by the United States and other nations is utilized as part of the IML-2 mission. The cooperative arrangement between the United States and its international partners includes sharing data, biological samples, and equipment, which reduces cost and allows the benefits of research to be extended to the world community.



Biorack System

a multipurpose habitat for preserving and handling samples



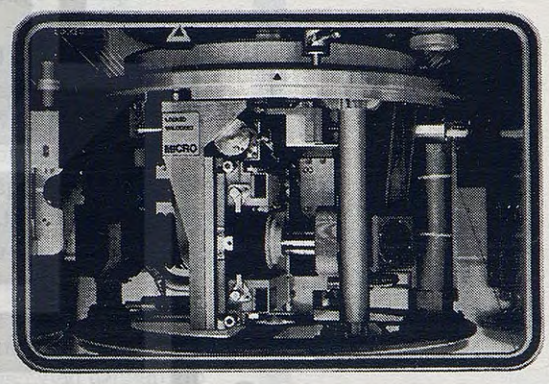
Developed by ESA, the Biorack is a multipurpose facility for investigating the effects of microgravity and cosmic radiation on isolated cells, tissues, bacteria, small animals, and plants. It has two incubators, a cooler, and a glovebox for growing, preserving, and handling samples. Subjects for IML-2 Biorack experiments include human and animal cells, yeast, bacteria, fruit flies, sea urchins, newts, jellyfish, and plant seedlings. Scientists from seven countries will use the Biorack in 19 experiments to study the following phenomena:

- **Immune system**—To counteract disease, the body activates T- and B-lymphocyte cells, which multiply to fight disease or infection. Previous space flight experiments have indicated that the activation and proliferation of these cells are inhibited by more than 90 percent in space flight. A number of the Biorack investigations explore processes, such as cell communication and movement and the interaction of antibodies, to determine if they change the functioning of the immune system in microgravity. The knowledge acquired could provide important insights into the causes and treatments of autoimmune diseases and other situations in which the immune system is compromised (e.g., patients under radiation, chemotherapy, and stress).
- **Skeletal system**—Previous data taken from crewmembers and animals in space flight have shown that the lack of gravitational force on bones causes bone atrophy and calcium loss. This effect on the body could inhibit the ability of crewmembers to function in Earth's gravity after an extended mission. In several Biorack experiments, scientists will examine the skeletal systems of various organisms, the long bones of embryonic mice, sea urchin larva, and other tissue from mice to determine the extent of bone atrophy in the microgravity environment. The results of these investigations could provide valuable insight into diseases such as osteoporosis, which affects elderly people on Earth.
- **Organism development**—Until space flight, organisms have developed in a 1-g (Earth gravity) environment. Several experiments will be undertaken to determine how organisms reproduce and develop without gravity and the extent to which microgravity affects cell division and differentiation as embryonic development takes place. Scientists will investigate the reactions to microgravity of the fruit fly and fertilized frog eggs to assess the effects of microgravity on organism reproduction and development. The results will provide information on the processes of fertilization, fetal development, and birth defects.

- **Plants**—For extended-duration space travel, plants will have to be grown in microgravity in a controlled ecological environment. Previous space flights have indicated that plant development is altered in microgravity. Using the Biorack, scientists will study lentil seedlings and several other species of plant to explore how plants develop in the space environment. Fixed samples, living roots, and protoplasts will be returned to Earth for genetic analysis. This research could provide valuable insight into crop growth and development.
- **Radiation**—Although the spacelab is equipped with special radiation shielding, cosmic radiation does penetrate the space vehicle. Previous investigations have shown that cells exposed to both radiation and microgravity may be damaged more than cells exposed to only one effect. In one Biorack study, scientists will investigate which cellular changes are caused by radiation, microgravity, or both; and, in two other investigations, they explore the effects of microgravity on the ability of cells to repair themselves after suffering radiation-induced damage.

The NIZEMI

a slow rotating centrifuge and microscope

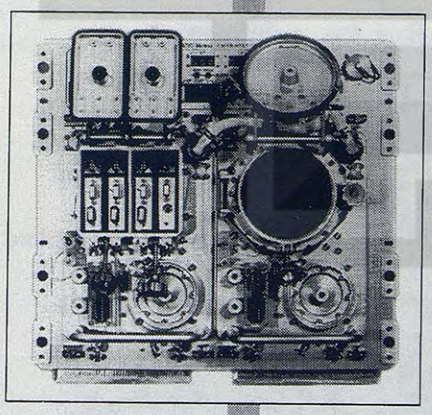


Developed by DARA, the NIZEMI is used to observe samples under variable g-forces (reached through acceleration). The primary hardware is a sophisticated research microscope mounted flat on the centrifuge turntable. Living organisms and inorganic samples are placed on the centrifuge to undergo gravitational force from 10^{-3} g (1/1000 of Earth gravity) to 1.5 g. Scientists observe single cells and small organisms through the microscope, which has a maximum of 32X primary magnification; and they observe multicellular organisms through a macroscopic observation unit. By observing these organisms under various g-forces, scientists can determine the minimum level at which the organisms show a reaction. The NIZEMI will be used to conduct six experiments to determine the sensitivity, behavior, and movement of unicellular and multicellular organisms and two experiments with plants to examine growth patterns and orientation in relation to various levels of gravity.

Aquatic Animal Experiment Unit

a habitat for aquatic creatures

Developed by NASDA and flown previously on the Spacelab-J mission, the AAEU is an aquarium for observing live fish and small amphibians for the duration of the IML-2 mission. It has two independent systems; four individual enclosures for animals, such as newts; and a water tank for fish. A special life support system for each unit supplies oxygen, removes carbon dioxide, eliminates waste, and regulates the temperature (from 15 to 25 °C). The crew views the animals through a window and accesses the newts through a port in each enclosure for the purposes of biological manipulation and removal of eggs. A video system can be attached to the viewing port to record observations of behavior, such as spawning, fertilization, embryonic stages, and vestibular function (inner ear, which provides balance and position information) for later analysis on the ground. The investigations involve



- Vestibular adaptation of fish
- Early development of a gravity-receptor organ
- Fertilization and embryonic development of newts
- Mating behavior of fish and development of their eggs.

Performance Assessment Workstation

a computer system for measuring perception, learning, memory, and reasoning

Developed by the USAF Armstrong Laboratories with NASA support, the Performance Assessment Workstation (PAWS) is a combination of six computerized performance tests to measure the cognitive skills of the astronauts. A variety of stresses encountered during space flight, including physical isolation, confinement, lack of privacy, fatigue, and changing work/rest cycles, affect the astronauts both physically and mentally. The purposes of this experiment are to measure the cognitive skills of the astronauts daily and distinguish between the effects of microgravity upon specific information processing skills affecting performance and the effects of the stresses they undergo in orbit. The astronaut will use a laptop computer to record responses to rotated images, spatial patterns, and questions on number recall, letter sequences, and math calculations and to track an unstable object on the screen using a precision trackball. The PAWS data will be useful to planners in scheduling work, maximizing productivity, and enhancing the job satisfaction of space travelers as they work for longer periods of time on the International Space Station. These tests have been used in training air crews and could be applied to workers in various industries.

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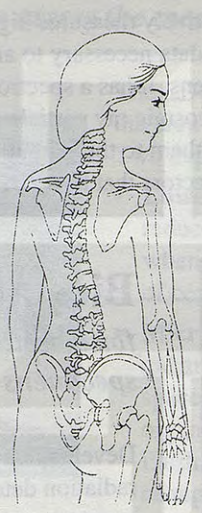
Errata Sheet

International Microgravity Laboratory 2
Life Sciences

Page 8 Under **Biostack**, the developing agency was erroneously stated as DARA. The German Research Establishment (DLR) developed the Biostack.

Spinal Change in Microgravity (SCM)

for investigating back pain reported by astronauts

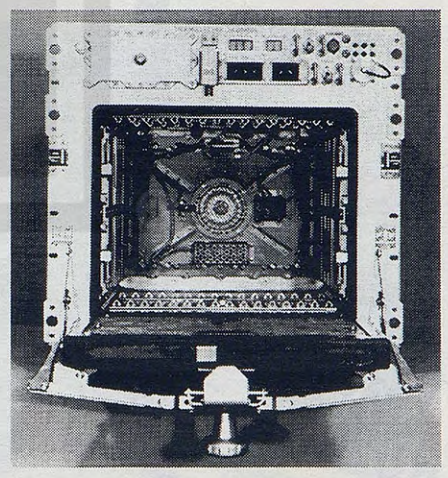


Developed by the CSA, the SCM experiment is designed to investigate the back pain reported by two-thirds of the astronauts on previous U.S. space flights. The back pain is believed to be the result of the lengthening and straightening of the vertebral column in microgravity, which is accompanied by an increase in height. The astronauts will measure their height periodically and describe any back pain and associated symptoms of spinal cord dysfunction, such as numbness. They also will take self-stereophotographs to provide information on spinal contour and range of motion, use nerve stimulation to determine the time it takes for a sensory impulse to travel from the foot to the brain, and use an ultrasound imaging device to measure the distance between the bones of the spinal column. The information gained could provide valuable insight into the problem of back pain experienced by many people on Earth.

Thermoelectric Incubator (TEI)

a habitat for storing cell cultures

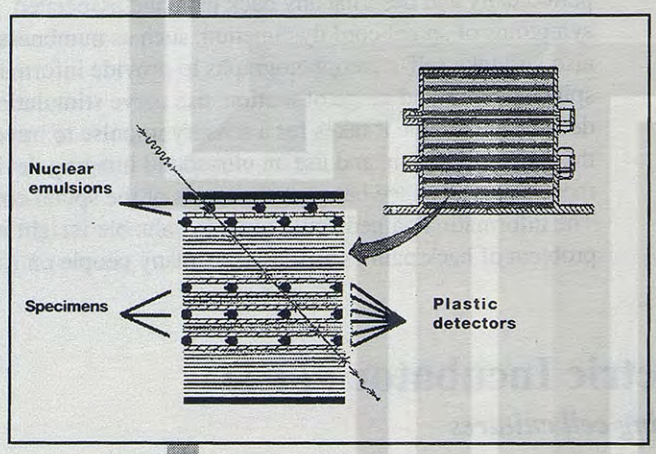
Developed by NASDA, the TEI is a general-purpose incubator that provides a controlled environment for cultures of mammal and plant cells. The petri plates and cell culture chambers will house and sustain slime mold, plant, and animal cells for observation and preparation for postflight analysis. The TEI will be used to perform three experiments involving the growth and differentiation of cells from plant embryos, the femur bones of adult rodents, and slime mold.



Real-Time Radiation Monitoring Device (RRMD)

for measuring radiation entering the Spacelab

Developed by NASDA, the RRMD actively measures high-energy cosmic radiation entering the Spacelab on orbit and rapidly collects data necessary to analyze the influence of radiation on the crew, payloads, and biological specimens. It has a spectroscopic sensor to measure the element energy and incident direction of each cosmic ray particle and an electronic control unit to record signals from the detector and transmit them to the ground during the mission. IML-2 data will be compared with data from Biostack detectors that have flown on several previous missions.



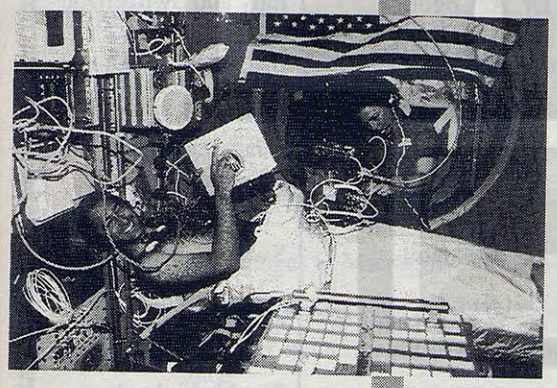
Biostack

for detecting radiation in biological specimens

Developed by DARA, the Biostack employs radiation detectors to monitor radiation that penetrates arranged biological specimens. The investigators use a wide spectrum of biological specimens, such as spores, yeast cells, shrimp eggs, and plant seeds, which have different levels of biological organization and radiation sensitivity. Data on the location of the trajectory of each heavy ion in the biological layer and the site of penetration inside the subject are recorded. Postflight studies of the specimens will be conducted to identify any changes in cellular and organic development, damage to the nuclei and other subcellular organs, and induction of mutations leading to somatic or genetic changes of biological significance. The experiment will also provide information on the spectrum of charge and energy level of cosmic radiation inside Spacelab.

Extended-Duration Orbiter Medical Project (EDOMP)

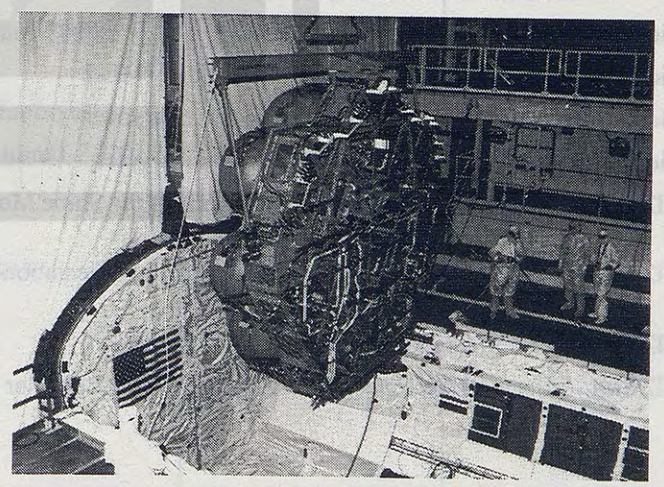
to assess the medical status and health of the crew



The EDOMP is a series of investigations for maintaining the health and safety of the crew and their environment during 13- to 16-day Space Shuttle missions. Two experiments will be conducted in the Spacelab on the IML-2 mission:

- **Lower Body Negative Pressure**—which investigates countermeasures to reduce postflight orthostatic intolerance (reduced blood flow to the brain when the astronaut stands, which causes dizziness and, in extreme cases, loss of consciousness).
- **Microbial Air Sampler**—which uses a hand-held, battery-powered centrifugal air sampler to collect samples of airborne bacteria and fungi in the spacecraft. This procedure allows the number and type of airborne microorganisms to be identified over the entire Shuttle mission. After analysis on Earth, recommendations will be made to counteract these environmental changes with air filtration devices.

Nine Detailed Supplementary Objective (DSO) experiments will be placed on the Shuttle middeck as part of the EDOMP. In one experiment, astronauts will be exposed to bright lights to assess how effective this technique is in resetting circadian rhythms and facilitating work shift changes. Two experiments are concerned with orthostatic intolerance: In one, heart rate and rhythm and blood pressure will be monitored during entry, landing, and Orbiter egress. Also, cardiovascular and cerebrovascular responses will be measured to characterize the responses to standing before and after space flight. Three experiments will characterize the vestibular system function during landing and egress. (In space flight, equilibrium is disrupted, causing space motion sickness.) There are three additional DSOs on the effects on the body of exercise routines; on gaze stability during walking, running, and jumping; and on the tendency of the crew to form kidney stones.



FOCUS

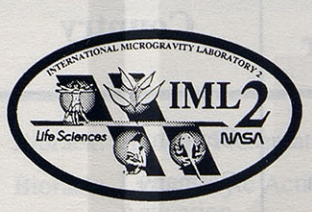
Summary of IML-2 Life Sciences Experiments

Experiment	Principal Investigator	Country
Biorack: Antigen Presentation and T-Cell Proliferation in Micro-G	Dr. A. Cogoli	Italy and Switzerland
Biorack: Lymphocyte Activation, Differentiation, and Adhesion Dependence on Activation	Dr. A. Cogoli	Italy and Switzerland
Biorack: Lymphocyte Movements and Interactions	Dr. A. Cogoli	Italy and Switzerland
Biorack: Effect of Microgravity on Cellular Activation: The Role of Cytokines (Cytokines)	Dr. D. Schmitt	France
Biorack: Effect of Microgravity on Cellular Activation: The Role of Cytokines (Phorbol)	Dr. D. Schmitt	France
Biorack: Cell Microenvironment and Membrane Signal Transduction in Microgravity	Dr. P. Bouloc	France
Biorack: Effect of Stirring and Mixing in a Bioreactor Experiment in Microgravity	Dr. A. Cogoli	Switzerland
Biorack: Molecular Biological Investigations of Animal Multi-Cell-Aggregates Reconstituted Under Microgravity	Dr. U.A.O. Heinlein	Germany
Biorack: Regulation of Cell Growth and Differentiation by Microgravity: Retinoic Acid-Induced Cell Differentiation	Dr. S.W. de Laat	The Netherlands
Biorack: The Sea Urchin Larva, a Potential Model for Studying Biomineralization and Demineralization Processes in Space	Dr. H.J. Marthy	France
Biorack: The Effects of Microgravity and Varying 1-g Exposure Periods on Bone Resorption; an in vitro Experiment	Dr. J.P. Veldhuijzen	The Netherlands
Biorack: Investigation of the Mechanisms Involved in the Effects of Space Microgravity on *Drosophila* Development, Behavior, and Aging	Dr. R. Marco	Spain
Biorack: Role of Gravity in the Establishment of Embryonic Axes in the Amphibian Embryo	Dr. G.A. Ubbels	The Netherlands
Biorack: Effect of Microgravity on Lentil Morphogenesis	Dr. G.E. Perbal	France
Biorack: Root Orientation, Growth Regulation, Adaptation, and Agravitropic Behavior of Genetically Transformed Roots	Dr. T.H. Iversen	Norway
Biorack: Plant Growth and Random Walk	Dr. A. Johnsson	Norway
Biorack: Dosimetric Mapping Inside Biorack on IML-2	Dr. G. Reitz	Germany
Biorack: Efficiency of Radiation Repair in Prokaryotes	Dr. G. Horneck	Germany
Biorack: Efficiency of Radiation Repair in Eukaryotes	Dr. G. Horneck	Germany
NIZEMI: Gravisensitivity and Geo(gravi)taxis of the Slime Mold *Physarum polycephalum*	Dr. I. Block	Germany
NIZEMI: Influence of Accelerations on the Spatial Orientation of the Protozoan *Loxodes striatus*	Dr. R. Hemmersbach-Krause	Germany
NIZEMI: Graviorientation in *Euglena gracilis*	Dr. D.P. Hader	Germany
NIZEMI: Effects of Microgravity on *Aurelia Ephyra* Behavior and Development	Dr. D. Spangenberg	U.S.A.

FOCUS

Summary of IML-2 Life Sciences Experiments

Experiment	Principal Investigator	Country
NIZEMI: Gravireaction in *Chara* Rhizoids in Microgravity	Dr. A. Sievers	Germany
NIZEMI: Gravisensitivity of Cress Roots (Cress)	Dr. D. Volkmann	Germany
NIZEMI: Lymphocyte Movements and Interactions	Dr. A. Cogoli	Italy and Switzerland
NIZEMI: Convective Stability of a Planar Solidification Front	Dr. K. Leonartz	Germany
AAEU: Mechanism of Vestibular Adaptation of Fish Under Microgravity	Dr. A. Takabayashi	Japan
AAEU: Early Development of a Gravity-Receptor Organ in Microgravity	Dr. M.L. Wiederhold	U.S.A.
AAEU: Fertilization and Embryonic Development of Japanese Newts in Space	Dr. M. Yamashita	Japan
AAEU: Mating Behavior of Fish (Medaka) and Development of Their Eggs in Space	Dr. K. Iijiri	Japan
SCM: Spinal Changes in Microgravity	Dr. J.R. Ledsome	Canada
PAWS: Performance Assessment Workstation	Dr. S.G. Shiflett	U.S.A.
EDOMP: LBNP: Countermeasures for Reducing Postflight Orthostatic Intolerance	Dr. J. Charles	U.S.A.
EDOMP: Microbial Air Sampler	Dr. D.L. Pierson	U.S.A.
EDOMP: Assessment of Circadian Shifting by Bright Light in Astronauts (DSO 484)	Drs. E. Baker and L. Putcha	U.S.A.
EDOMP: Orthostatic Function During Entry, Landing, and Egress (DSO 603)	Dr. J. Charles	U.S.A.
EDOMP: Visual-Vestibular Integration as a Function of Adaptation (DSO 604, two experiments)	Drs. M. Reschke and D. Harm	U.S.A.
EDOMP: Postflight Recovery of Postural Equilibrium Control (DSO 605)	Dr. W. Paloski	U.S.A.
EDOMP: Effects of Space Flight on Aerobic and Anaerobic Metabolism at Rest and During Exercise (DSO 608)	Dr. S. Siconolfi	U.S.A.
EDOMP: Inflight Assessment of Renal Stone Risk (DSO 610)	Dr. P. Whitson	U.S.A.
EDOMP: The Effect of Prolonged Space Flight on Head and Gaze Stability During Locomotion (DSO 614)	Dr. J. Bloomberg	U.S.A
EDOMP: Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight (DSO 626)	J. Fritsch-Yelle	U.S.A.
TEI: Gravity and the Stability of the Differentiated State of Plant Embryos	Dr. A.D. Krikorian	U.S.A.
TEI: Effects of Microgravity on Growth and Differentiation of Cultured Bone-Derived Cells	Dr. Y. Kumei	Japan
TEI: Differentiation of *Dictyostelium discoideum* in Space	Dr. T. Ohnishi	Japan
RRMD: Efficiency of Radiation Repair in Prokaryotes and Kinetics in Eukaryotes	Dr. T. Doke	Japan
Biostack: Radiation Detection in Biological Samples	Dr. D. Reitz	Germany



NASA

NASA is the U.S. agency that is dedicated to research and development of space science and technology. NASA manages the IML-2 mission, integrates the experiment facilities into a spacelab payload, and provides transportation for the experiments on the Space Shuttle/Spacelab. The agency is headquartered in Washington, D.C.

CSA

CSA is the focal point for Canada's space activities. Headquartered in Montreal, Quebec, the agency encourages and supports research, technology, and operations throughout Canada.

DARA

The central organization for planning and managing German space programs, DARA is headquartered in Bonn, Germany. One of its close partners is the German Aerospace Research Establishment (DLR), which is headquartered in Cologne, Germany.

ESA

ESA sponsors space research and technology among 13 member countries (Austria, Belgium, Denmark, France, Germany, Ireland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom), one associate member (Finland), and one country (Canada) under a cooperative agreement. The agency is headquartered in Paris.

CNES

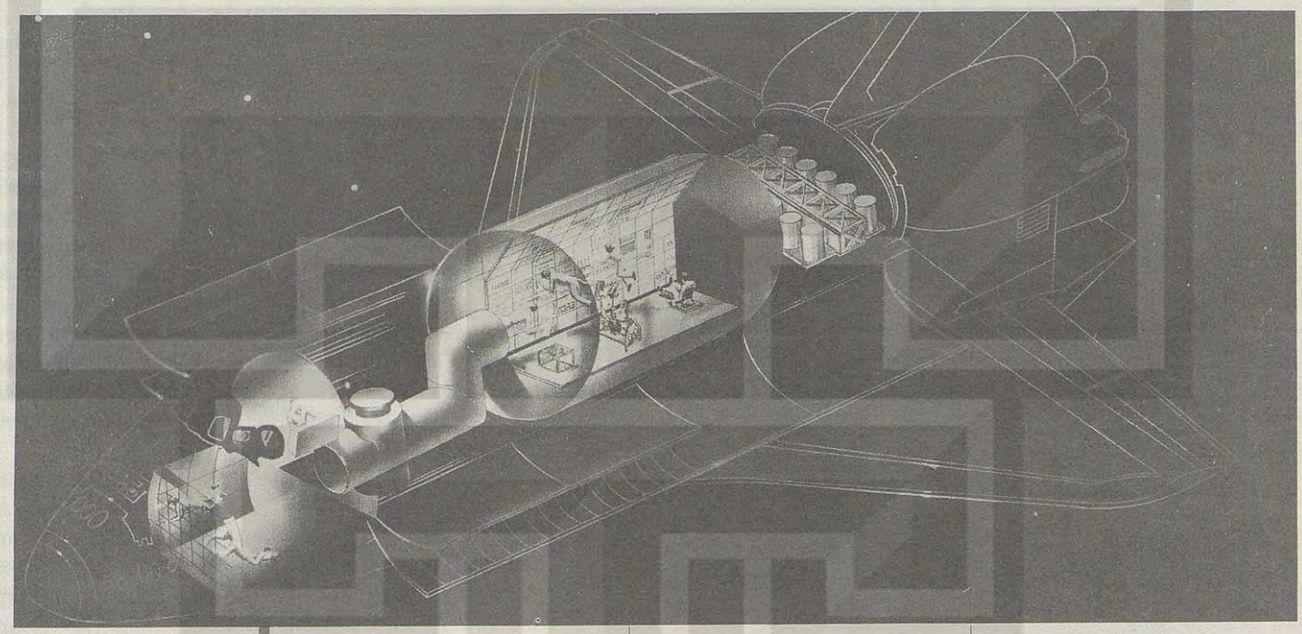
CNES is responsible for developing French space activities. In its program of basic research, CNES works with the scientific community, using the laboratories of the National Scientific Research Center, universities, and other organizations in France. CNES is headquartered in Paris.

NASDA

NASDA is responsible for many of Japan's space activities, which include exploring the practical applications of the space environment, conducting microgravity research, and developing satellites. NASDA is headquartered in Tokyo.

Microgravity Science & Applications Division

The Second International Microgravity Laboratory (IML-2)



THE SECOND INTERNATIONAL MICROGRAVITY LABORATORY (IML-2)

The Second International Microgravity Laboratory (IML-2), scheduled to fly on STS-65 in July of 1994, is the next in a series of cooperative NASA Space Shuttle missions dedicated to international microgravity and life science research.

The International Microgravity Laboratory program was established in 1983 by NASA and its international space agency partners to conduct space research using the European Space Agency developed Spacelab module. IML-2 allows U.S. researchers the use of sophisticated research apparatus developed by other countries, while also allowing international investigators the opportunity to conduct research aboard the Space Shuttle with no direct flight expenses. IML-2 also will provide a preview of science operations and flight hardware on the International Space Station.

The first IML mission flew in January of 1992, successfully completing eleven U.S. microgravity experiments. Research was conducted in protein crystal growth, vapor and solution crystal growth of electronic materials, solidification of metal model alloys, and critical point fluid physics. The IML-2 payload consists of 78 major experiments; of these, eleven are sponsored by the Microgravity Science and Applications Division (MSAD) and four by the Life Sciences Division of NASA's Office of Life and Microgravity Sciences.

The image of astronauts floating inside the Space Shuttle suggests that they have somehow escaped gravity while in orbit—but this is not the case. Zero gravity is virtually impossible to achieve: one would have to travel more than seventeen times farther than the moon to reduce Earth's gravitational pull to one millionth of that at Earth's surface. The pull of gravity in low orbit is not much different than on the ground—about 10% less. Why then do orbiting laboratories such as the Space Shuttle, or a space station such as Russia's Mir, offer conditions of near weightlessness or microgravity?

The term microgravity ("micro" meaning small) suggests the reduction of gravity, but the near weightlessness of an orbiting spacecraft is actually due to the spacecraft being in a state of continuous free fall. Engines propel the spacecraft forward, and gravity pulls it (and everything inside) toward the Earth. The combination of these two forces results in the Spacecraft "falling" around the Earth in an orbit, establishing a microgravity environment onboard. ◆


Protein crystal grown in µg

Biotechnology


Flame in µg

Combustion


Air bubbles in liquid in µg

Fluid Physics


Semiconductor crystal grown in µg

Materials Science

NASA'S MICROGRAVITY SCIENCE & APPLICATIONS PROGRAM

NASA's Microgravity Science and Applications Division sponsors research on important physical, chemical, and biological processes in a microgravity environment. Microgravity scientists conduct experiments in four major research areas:

- *Biotechnology* researchers use microgravity to grow improved protein crystals to determine the protein's structure and its relation to function; researchers also study the benefits of low gravity for culturing human tissues
- *Combustion* scientists use microgravity to simplify the study of various combustion processes, such as flame spread over a surface, thus providing insights into the behavior of fundamental combustion problems
- *Fluid Physics* research reveals the physics of gas and liquid behavior in applied and basic science
- *Materials Science* researchers use microgravity to study how the processing of a material affects its final structure, and the resulting properties

MICROGRAVITY RESEARCH ON IML-2

NASA's Microgravity Science and Applications Division is building on the previous research conducted on IML-1 by sponsoring eleven new microgravity investigations on IML-2. These investigations will utilize the wide variety of international hardware that the IML-2 program makes accessible to U.S. researchers.

BIOTECHNOLOGY

Protein Crystal Growth

Conditions on Earth limit the size and quality of protein crystals. The microgravity environment of space, however, can allow the growth of larger, more highly ordered crystals. MSAD sponsored investigator Dr. Alexander McPherson, Jr. of the University of California at Riverside will use the European Space Agency's (ESA) Advanced Protein Crystallization Facility (APCF) to grow high quality crystals of nine different proteins. The experiment will determine the effects of microgravity on the size and quality of macromolecular crystals and evaluate the Liquid-Liquid method of crystallization.

Electrophoresis

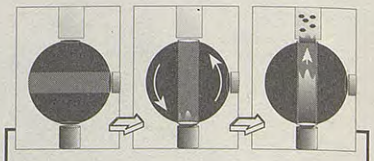
Electrophoresis in a free-flowing solution is a unique process that separates biological materials into individual components using an electric field. IML-2 will utilize both the Japanese Space Agency's (NASDA) Free-Flow Electrophoresis Unit (FFEU) and the French Space Agency's (CNES) Applied Research on Separation Methods Using Space Electrophoresis (RAMSES) apparatus. In each electrophoresis unit, a solution flows through a thin rectangular chamber. When a protein solution or cell population is injected into a flowing buffer solution, an electric field can be used to separate proteins as they travel through the chamber.

Dr. Wesley C. Hymer of the Pennsylvania State University will use the FFEU to separate the growth hormone prolactin from rat pituitary cells. The experiment will determine the possible negative influence that microgravity has the on secretion of these hormones. Dr. Robert S. Snyder of the NASA Marshall Space Flight Center will employ RAMSES to study the forces that govern electrophoresis. The investigation will examine how the shape of the sample flow is modified by the electric field, the flow of the carrier solution, and variations in the electrical conductivity of the solution.

FLUID PHYSICS

Bubbles, Drops, and Particles

Microgravity allows researchers to study fluid phenomena normally masked by the effects of gravity. This research is also relevant to materials processing: bubbles and drops are encountered in various materials processes, such as solidification and preparation of

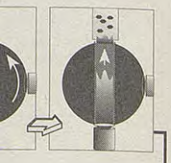


APCF
Advanced Protein Crystallization Facility

The Advanced Protein Crystallization Facility is a compact, multi-user facility developed by the European Space Agency to carry out protein crystal growth studies on orbit. APCF research focuses on two major objectives: 1) to provide difficult to produce, biologically important crystals for analysis, and 2) to determine the physical mechanisms that govern protein crystal growth.

The arrangement of atoms within a protein molecule largely determines its biological function. Scientists use the X-ray diffraction technique to determine this arrangement or structure. Conditions on Earth limit the size and quality of protein crystals, but the microgravity environment of space allows the growth of larger, more highly ordered crystals.

The APCF is designed to use three methods of protein crystal growth. The first will use liquid-liquid diffusion, or free interface diffusion, in which a protein solution and a salt solution are separated by a buffer and are allowed to slowly flow together (see figure above). The second will employ the dialysis method, with protein and salt solutions separated by a porous membrane. The third method will use the vapor diffusion, or hanging drop technique, where crystals form inside a drop of protein solution as solvent from the drop diffuses to a reservoir. Information gained from crystals grown in the APCF will assist investigators in evaluating techniques and defining processes that may lead to a better understanding of protein structure and function.



Characteristics of a Microgravity Environment

A microgravity environment has unique characteristics—such as substantially reduced buoyancy flows, sedimentation, and hydrostatic pressure—that allow the investigation of phenomena and processes that are difficult or impossible to study on Earth due to normal gravity. In microgravity, it becomes possible to isolate and control gravity-related phenomena and take measurements that generally afford greater accuracy than can be achieved on Earth.

composite materials. In order to advance materials research in microgravity, researchers need a better understanding of the fluid processes that play a role in the production of most materials. It is therefore important to understand the motion of bubbles and drops and to learn to manipulate them under low-gravity conditions where buoyancy is negligible.

Two MSAD investigators will use the ESA Bubble, Drop, and Particle Unit (BDPU) aboard IML-2 to conduct microgravity experiments. Dr. R. Shankar Subramanian of Clarkson University will study the movement and shape of gas bubbles and liquid drops under the action of a temperature gradient. Results from these experiments will be compared with predictions from theoretical models to improve our understanding of bubble and drop motion in materials processing. Prof. Jean N. Koster from the University of Colorado will examine the interaction of two surface-tension gradient forces of different magnitudes on flow patterns in a multi-layered immiscible fluid system (fluids that do not mix, such as water and oil). Researchers hope that these results will eventually lead to criteria that improve crystal growth.

Low Temperature Fluid Physics

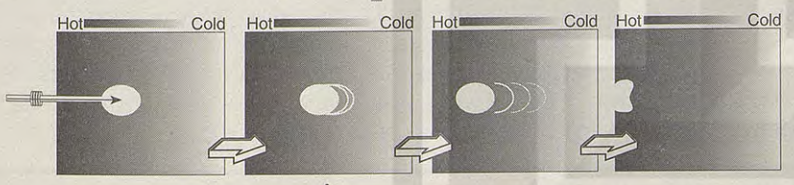
Prof. Richard A. Ferrell of the National Institute of Standards and Technology will use ESA's Critical Point Facility (CPF) to study the critical point properties of a single fluid. As the temperature of the fluid is lowered below the critical point, the fluid undergoes a phase transition and transforms into two coexisting phases, liquid and gas. The experiment will examine the competition and interaction of pressure and thermal diffusion as energy transport mechanisms near the critical point. The data obtained will be useful in designing subsequent critical point fluid experiments to minimize the role of heat diffusion.

MATERIALS SCIENCE

Containerless Processing

Investigators will take advantage of the German Space Agency's (DARA) Electromagnetic Containerless Processing Facility (TEMPUS) to process material samples in a containerless environment, thus eliminating the possibility of contamination from container walls. The samples are positioned within an electromagnetic coil, melted, and then cooled. The resulting data helps researchers understand the chemical, physical, and thermodynamic properties of their samples. Each experiment probes a fundamental property of the material in a manner that cannot be duplicated on Earth.

MSAD is sponsoring four containerless processing experiments that make use of TEMPUS. Dr. Robert J. Bayuzick of Vanderbilt University will describe the distribution of temperatures during the process of solidification to determine the necessity for containerless processing in low Earth orbit. The nucleation temperature of the sample and the rates of growth of the solid will be recorded for comparison with Earth-based results to further the understanding of nucleation phenomena. Prof. Merton C. Flemings and Dr. Julian Szekely



The figure above shows how a bubble moves toward a hot wall due to the change in density from a low to a high temperature.

BDPU Bubble, Drop, and Particle Unit

The European Space Agency's Bubble, Drop, and Particle Unit (BDPU) is a multi-user facility designed to investigate liquids under the influence of temperature, concentration profiles, and electric fields. Research in this facility will study fluid behavior such as thermocapillary flow, bubble growth, evaporation, and condensation. Earth's gravity-induced convection, buoyancy, and sedimentation often mask these interactions. Experiments conducted in the BDPU will be enable experimenters to quantitatively measure the more subtle fluid processes.

The BDPU uses interchangeable experiment-dedicated fluid cells. These cells can incorporate mechanical or acoustic stirrers for fluid homogenization, injectors for bubbles or droplets, and heaters or cooling elements to impose temperature differences within the fluid. The BDPU core provides a series of standard interfaces for the interchangeable test containers. The various test cells will be used to study how bubbles and drops react in liquids with varying temperatures and concentrations, how they affect the process of solidification, how convection affects liquid layers under different temperature conditions, and how evaporation and condensation affect bubble creation and growth.

of the Massachusetts Institute of Technology, and Dr. William L. Johnson of the California Institute of Technology will each use TEMPUS to undercool (reduce the temperature of a sample to below the freezing point while maintaining it in the liquid state) materials to compare against theories of crystallization and glass formation, to study the viscosity and surface tension of undercooled metallic melts, and to examine the effects of undercooling on the growth rate of the solid phase of metallic melts.

Liquid Phase Sintering

Dr. Randall M. German of Pennsylvania State University will use the NASDA-developed Large Isothermal Furnace (LIF) to determine the influence of gravity on the micro- and macrostructures of heavy alloy tungsten-nickel-iron systems. The material will be heated so that the iron and nickel form a liquid surrounding the tungsten. This process, called liquid phase sintering, is used to produce alloys of novel composition. This investigation will add to ground-based research examining the role that gravity plays in distorting the microstructure of samples sintered on Earth.

LIFE SCIENCE RESEARCH ON IML-2

NASA's Life Sciences Division of the Office of Life and Microgravity Science is sponsoring four new life science experiments on IML-2. These investigations also will utilize the wide variety of international space biology hardware and U.S.-developed performance assessment hardware that the IML-2 program makes accessible to U.S. researchers.

Space Biology

Dr. Michael L. Wiederhold of the University of Texas Health Science Center, San Antonio will utilize the NASDA developed Aquatic Animal Experiment Unit (AAEU) to determine the effect gravity plays in the development of newt otoliths. The otolith is the sensory receptor located in the inner ear that allows many organisms, including humans, to sense gravity. The experiment will determine the development stage at which otoliths first appear in newts and the rate of growth. The data gained from the experiment will be compared to data from ground-based experiments to determine whether gravity affects otolith growth rate.

DARA's Slow Rotating Centrifuge Microscope will be used by Dr. Dorothy B. Spangenberg of Eastern Virginia Medical School to study gravity's effect on the swimming/pulsing/orienting behavior development of ephyrae (the larval, free-swimming medusoid stage of jellyfish). Results from the experiment will help improve the understanding of microgravity's effects on the developmental process of animals and gravity's role in the behavioral and developmental responses of organisms on Earth.

Dr. Abraham D. Krikorian of the State University of New York at Stony Brook will use the NASDA developed Cell Culture Kit (CCK) to test the critical stages of embryo growth using cultured carrot and daylily cells. The experiment will test and profile these stages to gain a better understanding of embryo growth under microgravity conditions essential to future plant-based biotechnologies in space.

Human Factors

Performance Assessment Workstation (PAWS) developed by Dr. Samuel G. Schiflett of USAF Armstrong Laboratory is a computer system for measuring perception, learning, memory and reasoning. PAWS is a combination of six computerized performance tests to measure the cognitive skills of the astronauts in order to distinguish between the effects of microgravity upon specific information processing skills affecting performance and the effets of the stresses they undergo in orbit. The PAWS data will be useful to planners in scheduling work, maximizing productivity, and enhancing the job satisfaction of space travelers as they work for longer periods of time on the International Space Station. ■

MISSION SUMMARY

Space Shuttle Orbiter: Columbia (OV-102)
Launch Site: Kennedy Space Center
Operations Altitude: 296 KM
Orbital Inclination: 28.5 º
Mission Attitude: Gravity Gradient Orbit
Crew Size: 7
Prime Landing Site: Kennedy Space Center
Primary Payload: Spacelab

CREW

Col. Robert D. Cabana, Mission Commander
Lt. Col. James Donald Halsell, Jr., Pilot
Lt. Col. Carl E. Walz, Mission Specialist
Richard J. Hieb, Payload Commander
Dr. Leroy Chiao, Mission Specialist
Dr. Donald A. Thomas, Mission Specialist
Dr. Chaki Mukai, Payload Specialist (NASDA)
Dr. Jean-Jacques Favier, Alternate Payload Specialist

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Microgravity Science and Applications Division

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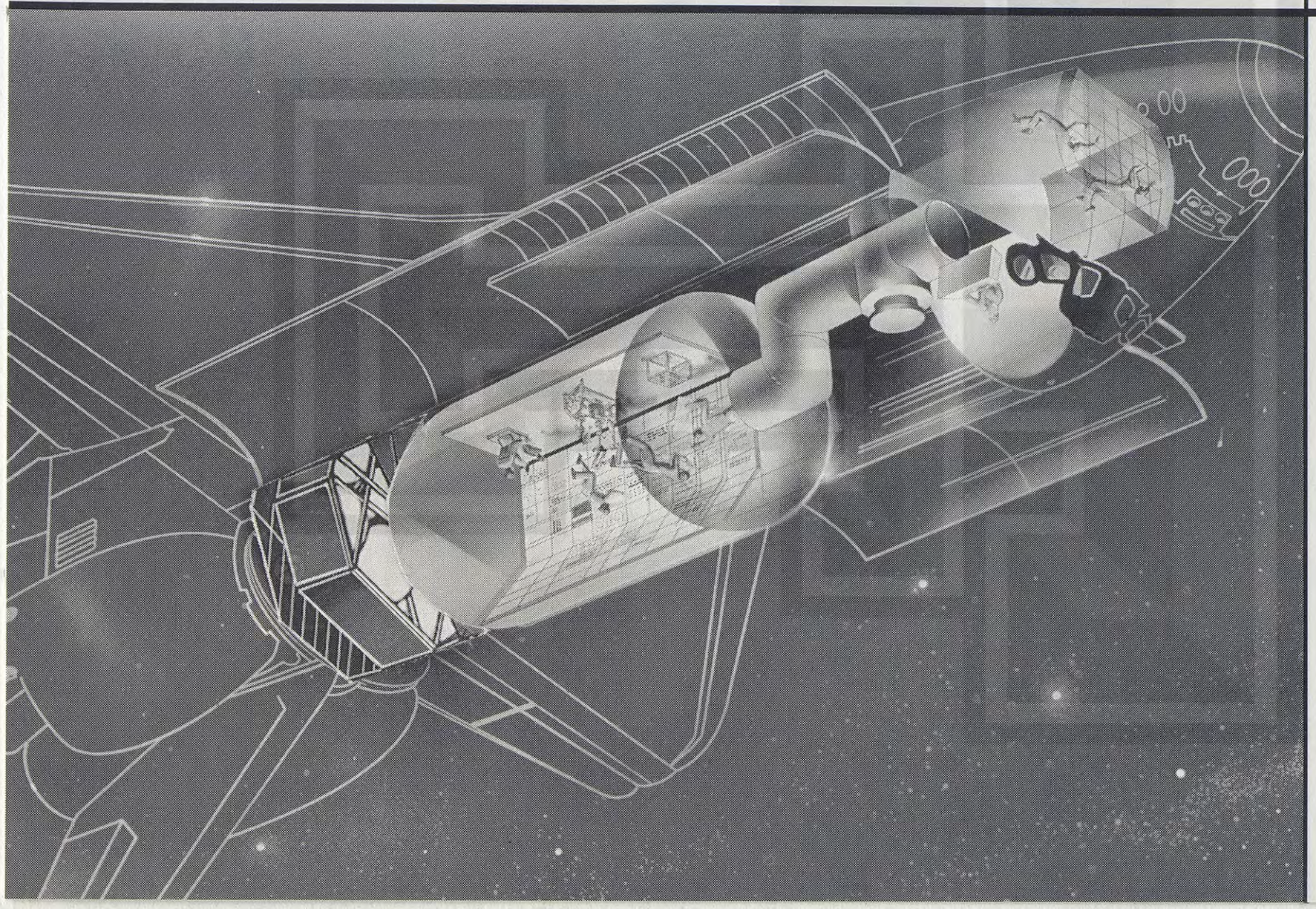
STS-65/IML-2

Focus



Office of Life and
Microgravity Sciences
and Applications

Microgravity Sciences
and Applicatons Division

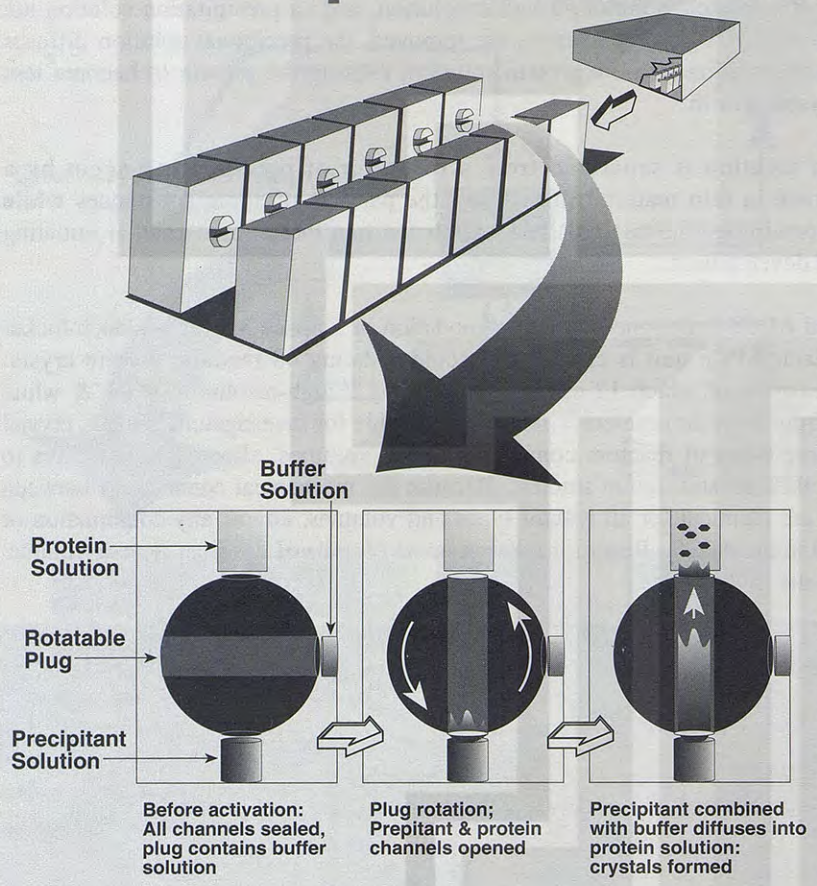
Focus

APCF

Advanced Protein Crystallization Facility

Introduction

The European Space Agency's Advanced Protein Crystallization Facility (APCF) is a compact, multi-user facility to carry out protein crystal growth studies in microgravity. Research using the APCF has two important objectives: to provide difficult-to-produce, biologically important protein crystals for analysis, and to determine the physical mechanisms that govern protein crystal growth.



Schematic of APCF showing 12 growth chambers. The bottom three diagrams show the liquid-liquid diffusion technique, which Dr. McPherson of the University of California at Riverside will use.

Proteins are complex molecules responsible for a great many biochemical functions essential to life on Earth. Scientists strive to determine the structure and function of proteins to better understand living systems, and to develop pharmaceutical drugs. Protein structures are determined by X-ray analysis of protein crystals. Recent experiments have shown that microgravity-grown crystals often provide better structural data than their ground-grown counterparts.

Overview and Significance

Protein structure determination is one of the most dynamic fields of research in science and medicine. The arrangement of atoms within a protein molecule largely determines its biological function. In the pharmaceutical industry, researchers use this information to design drugs that bind to a specific protein, blocking chemically active sites. Such a drug fits the protein like a key in a lock to "turn off" the protein's activity, thus regulating metabolic processes.

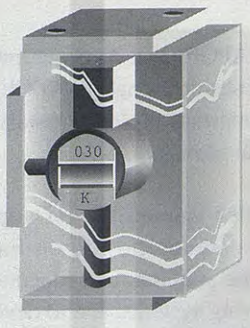
X-ray diffraction is the primary technique scientists use to determine the structure of large proteins. Protein crystals are exposed to tightly focused beams of X-rays which are diffracted (scattered) by the crystal and measured using electronic detectors or photographic plates. By analyzing the diffraction patterns, scientists can work to determine the protein's 3-dimensional structure.

The major obstacle in structure determination is obtaining the high-quality crystals needed for X-ray diffraction. Many proteins that interest medical researchers have not produced crystals of adequate size and quality to allow X-ray diffraction data to be collected. Gravity-induced movement within the growth solution such as fluid flows caused by density differences and sedimentation (settling and separation of heavier elements in a fluid) can influence protein crystal growth. Experiments in space have demonstrated that these effects are reduced in microgravity, often improving crystal characteristics.

Experiment Hardware and Operations

Crystal growth in the APCF is initiated by causing a protein solution to supersaturate (a condition where there is more protein than can be dissolved in the volume of fluid). As a result of this supersaturation, the protein crystals "fall out" of solution and begin to grow. Supersaturation is achieved by allowing the diffusion (movement of atoms or molecules from an area of high concentration to low) of water out of the protein solution, or by introducing precipitant into the solution, thereby increasing the concentration of protein within the solution or changing the solubility of the protein. The APCF is the first space facility to support the following three types of protein crystal growth techniques:

APCF
Advanced Protein Crystallization Facility



Protein crystal growth liquid-liquid diffusion chamber

Vapor diffusion: The protein solution is suspended as a drop at the end of a syringe tip in a chamber surrounded by material soaked in a concentrated precipitation agent. As water migrates from the protein solution to the precipitant solution, the concentration of protein within the drop increases. Eventually, it supersaturates, and crystal growth begins.

Liquid-liquid diffusion: The protein solution, a buffer solution, and a precipitation solution are initially separated by shutters. When the shutters are removed, the precipitant solution diffuses through the central buffer solution into the protein solution, causing the protein to become less soluble and initiating crystal growth.

Dialysis: The protein solution is separated from a reservoir of precipitating agent by a semipermeable membrane (a thin material that allows the passage of some substances while blocking others). The precipitant moves across the membrane into the protein solution initiating precipitation and crystal development.

The computer-controlled APCF is designed for accommodation in a Space Shuttle middeck-locker or Spacehab locker. Each APCF unit is capable of accommodating 48 modular protein crystal growth chambers, or reactors, of which 12 can be observed by a high-resolution black & white video camera. Images from the video camera will make it possible for investigators to study crystal growth history. The three types of reactors come in different volumes, allowing researchers to optimize conditions for their crystallization studies. Because the mechanical connections between reactors and the APCF are identical for all reactor types and volumes, almost any combination of reactors can be installed in the APCF. Reactor exchange, even of units of different type or volume, is possible very close to the flight date.

Carrier
Space Shuttle middeck locker/Spacehab locker

Physical Characteristics
- **Dimensions:** 40.5 x 24.0 x 50.0 cm.
- **Mass:** 26.3kg
- **Power:** 65 Watts
- **Sample material:** Experiment specific protein
- **Capacity/flight:** Up to 48 samples/APCF
- **Process temperature:** Any (fixed) temperature between +4˚C and +20˚C (±0.3˚C)

Data Acquisition
- Return of crystals for analysis on Earth
- B/W CCD video camera

Scheduled Flight
- STS-65/Second International Microgravity Laboratory (IML-2) Mission

Development Center
European Space Agency
European Space Research and Technology Centre (ESTEC) Noordwijk, The Netherlands

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Microgravity Science & Applications Division

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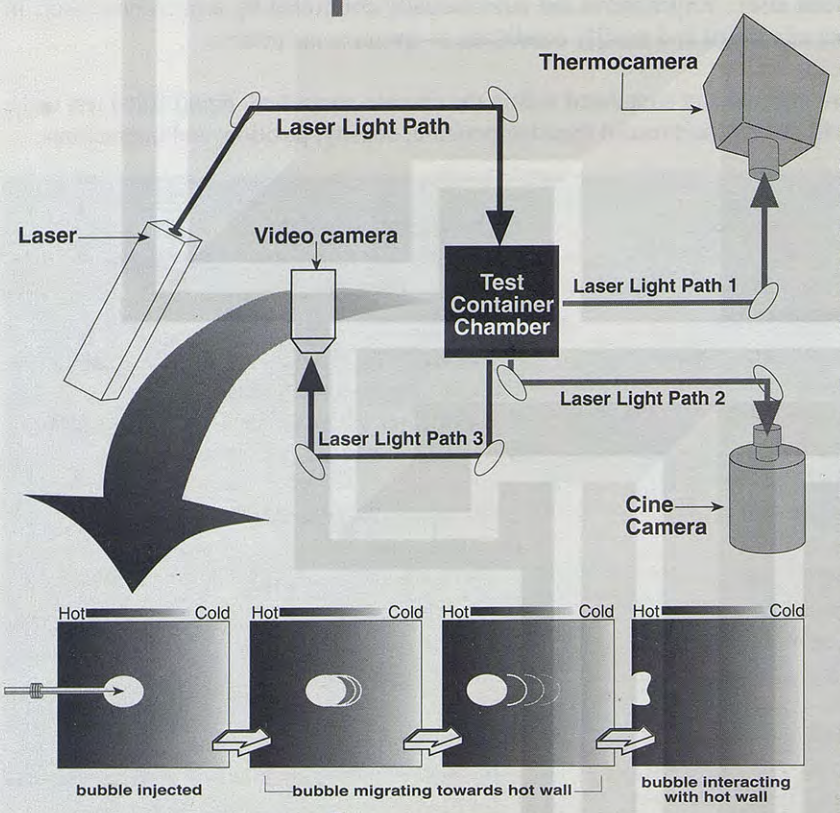
Focus

BDPU

Bubble, Drop and Particle Unit

Introduction

The European Space Agency's Bubble, Drop and Particle Unit (BDPU) is a multi-user facility for investigating liquids under the influence of temperature, concentration profiles, and electric fields. Researchers will study fluid behaviors and interactions such as thermocapillary flows (fluid motions generated by temperature differences along the surfaces of liquids), bubble growth, evaporation, and condensation. Such phenomena are difficult to observe on Earth because their effects are masked by gravity-induced fluid movements. Knowledge gained through the use of the BDPU will test and refine theories of fluid behavior, and may be used to improve the design of spacecraft life support and fuel management systems, as well as materials processing both on Earth and in space.



BDPU schematic showing how a bubble moves toward a hot wall due to the change in density from a low to a high temperature.

Overview and Significance

Our intuitive expectations of how fluids (liquids or gases) normally behave are based on their actions under the influence of gravity. For example, hot air rises because it is less dense than cooler air, and gravity's pull similarly induces convection—flows within a fluid caused by density differences. Muddy water will clear when left standing because gravity also causes sedimentation (the separation and settling of heavier elements from lighter ones) of soil particles suspended within the water.

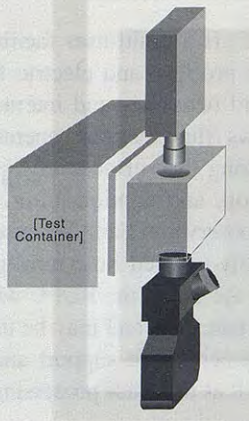
In a microgravity environment, such gravity-driven convective flows are minimized, and other more subtle fluid movements, such as thermocapillary flows, can be observed. The flows become the main mechanism of heat transfer within fluids. Suspended particles, bubbles, and liquid drops behave differently in microgravity. For example, a drop of liquid will form an almost-perfect sphere (instead of the familiar teardrop shape) as drop behavior becomes dominated by surface tension effects instead of gravity. The BDPU will allow researchers to explore these subtle aspects of fluid physics that are normally hidden by the effects of Earth's gravity.

The knowledge of fluid physics gained in space is not only important to basic science, but is also the key to new technologies. The behavior of fluids is at the heart of many phenomena in materials processing, biotechnology, and combustion science. Surface tension-driven flows (fluid flow from hot regions to cold) affect semiconductor crystal growth, welding, and the spread of flames on liquids. The dynamics of liquid drops are an important aspect of chemical process technologies and in meteorology. Research conducted with the BDPU will increase our understanding of fluid physics and provide a foundation for predicting, controlling, and improving a vast range of technological processes.

Experiment Hardware and Operations

The BDPU uses interchangeable experiment-dedicated fluid cells (7 cm. x 7 cm. x 5 cm.) that can be exchanged by a crewmember. These cells can incorporate mechanical or acoustic stirrers for fluid mixing, injectors for bubbles or droplets, and heating and cooling elements to impose temperature differences within the fluid. A manual extraction system allows the crew to remove bubbles from the sample. The test container can generate an electric field of as much as 28 volts across the sample by using capacitor plates.

BDPU
Bubble, Drop and Particle Unit



BDPU Cameras and Test Containers

The BDPU core provides a series of standard interfaces for the interchangeable test containers. Modular optics components support several different diagnostic techniques, including Schlieren (shadowgraph) imaging and infrared imaging. The sample can be illuminated using fluorescent lamps, or a Helium-Neon laser. Experiments are automatically controlled by a microprocessor; in addition, a crewmember can adjust and modify conditions to optimize the process.

As bubbles or drops are injected and stimulated within the climate-controlled, liquid filled test cells, cameras and sensors will observe and record their temperature, density, position, and interactions.

Carrier
Shuttle/Spacelab

Physical Characteristics
- **Dimensions:** 34 Panel Units (1PU = 4.5 mm)
- **Mass:** 180 kg (approx.)
- **Power:** 600 Watts Nominal
  (800 Watts Peak 34.5 kWh)
- **Sample Volume:** up to 343 cc.
- **Bubble, drop diameter:** 1 mm to 20 mm
- **Temperature control:**
  Operations between 0°C and 120° C
  Temperature gradients of up to 40° C
- **Light Sources:** 1.8 mW HeNe laser
  Fluorescent lamp for back-lighting sample cell

Data Acquisition
- Infrared camera
- Photo camera
- Cinema camera
- Interferometer with CCD camera

Scheduled Flights
STS-65/Second International Microgravity Laboratory (IML-2) Mission

Development Center
European Space Agency (ESA)
European Space Research and Technology Centre (ESTEC) Noordwijk, The Netherlands

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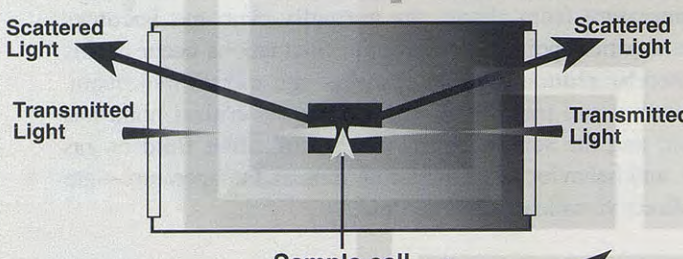
Microgravity Science & Applications Division

Focus

CPF
Critical Point Facility

Introduction

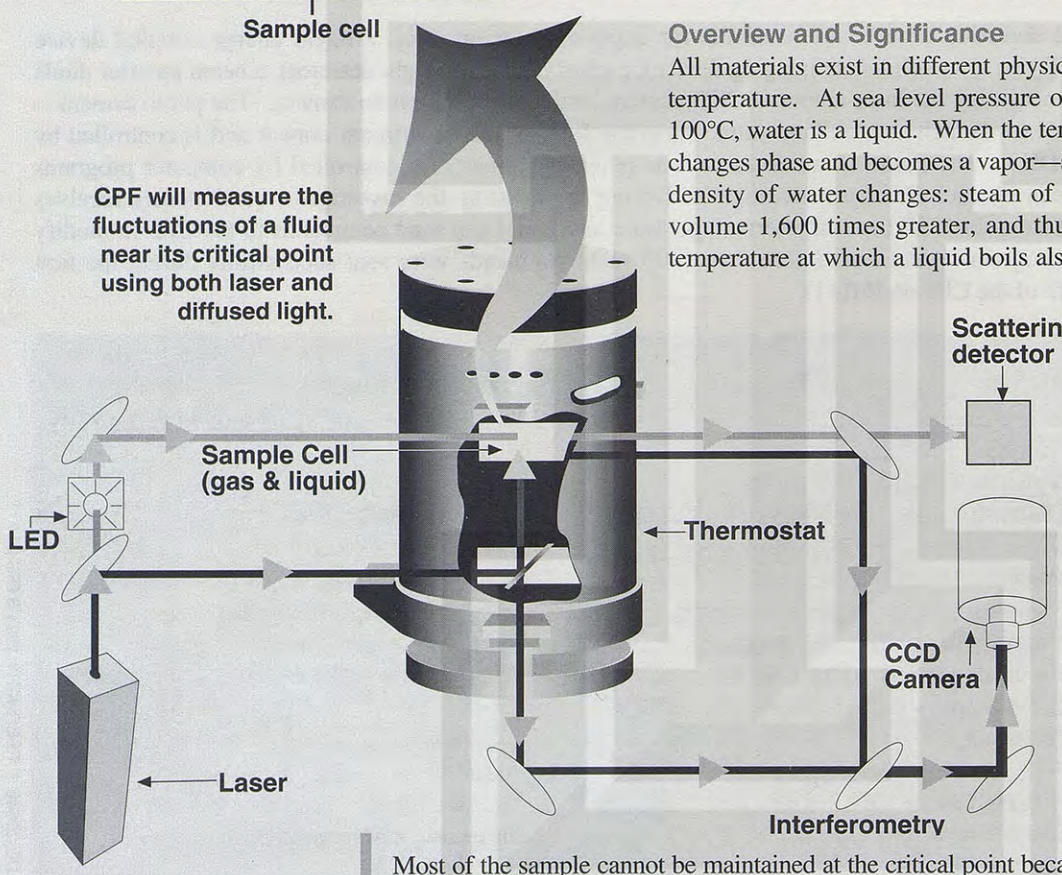
The Critical Point Facility (CPF) is a multi-user research device developed by the European Space Agency. Using the CPF, researchers will analyze the behavior of fluids at a condition when they are simultaneously a gas and a liquid—their "critical point." Scientists are interested in this unusual state of matter because critical point phenomena are common to many different materials. Understanding how matter behaves at the critical point can provide insight into a variety of physics problems ranging from phase changes in fluids to changes in the composition and magnetic properties of solids.



The CPF has already flown successfully on the first International Microgravity Laboratory mission (STS-42/IML-1) in January, 1992. Experiments scheduled for future flights will elaborate on previous work as well as explore new aspects of critical point phenomena.

Overview and Significance

All materials exist in different physical states that depend on pressure and temperature. At sea level pressure on Earth and at temperatures less than 100°C, water is a liquid. When the temperature rises above 100°C, the water changes phase and becomes a vapor—steam. During this phase transition, the density of water changes: steam of the same mass as liquid water has a volume 1,600 times greater, and thus is less dense than the liquid. The temperature at which a liquid boils also depends on pressure. If the pressure increases, the liquid will boil at a higher temperature and its density will be greater when it changes to vapor. The differences between liquid and vapor density decrease as pressure and temperature increase until—at the critical point—the liquid and vapor states have the same density. At the critical temperature and pressure, regions of the fluid fluctuate rapidly between liquid and vapor in a wave like manner. Experiments performed with the CPF will explore this unusual condition.



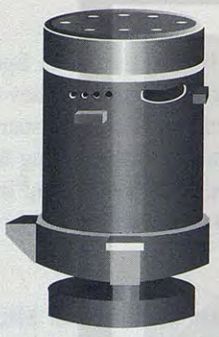
CPF will measure the fluctuations of a fluid near its critical point using both laser and diffused light.

In Earth's gravity, critical point experiments are difficult to perform. Most of the sample cannot be maintained at the critical point because the fluid's own weight compresses half of the sample to a density greater than the critical density, while the remaining half has a density less than that of the critical density. Only a thin portion of the sample between the two halves is at the critical density. The CPF experiments will take advantage of the reduced weight of materials in the microgravity environment of space to expand the critical zone, allowing researchers to perform measurements that cannot be made on Earth.

Experiment Hardware and Operations

The CPF will measure density fluctuations near the critical point through the use of laser light scattering and interferometry. Interferometry splits and subsequently reunites beams of light after

CPF
Critical Point Facility



CPF thermostat containing sample cell

they travel different paths. The two separated beams interact (interfere) with each other in such a way as to allow precise measurement of very small distances and thicknesses.

The sample gas held near its critical density is housed within the experimenter-supplied sample cells. The cells are installed in a high precision thermostat that holds them at a temperature between 30°C and 60°C, with an accuracy of one-thousandth of a degree centigrade (1 mC). As the sample approaches its critical pressure and temperature from above, the normally clear gas becomes opalescent (cloudy) as it passes through the critical point. Rapid density fluctuations occur at this point, which strongly scatter the light thereby reducing the intensity of the transmitted beam. Detectors measure these variations in scattered and transmitted light. After the critical point has been crossed, these fluctuations diminish, and the sample forms patches of either fluid or gas phases. These patches—their size, density, and behavior as a function of time and temperature—are then monitored by interferometry and by direct visualization of the fluid.

Five detection devices are available for experiment diagnostics: a linear charge coupled device (CCD) array (a solid-state imaging device), a photomultiplier (light detector), a beam monitor diode for measuring the laser output, a CCD camera, and a port for a photo camera. The photo camera—stored for launch and landing—attaches to the front of the experiment drawer and is controlled by the DHS. The Photo Camera, as well as other equipment, are controlled by computer programs written by each Principal Investigator. During the mission, the Investigator continuously receives data from the CPF (optical, thermal, pressure, etc.), and can send commands to the CPF to modify the program in real time (more than 1100 such commands were sent successfully during the first flight of the CPF on IML-1).

Carrier
Shuttle/Spacelab

Physical Characteristics
- **Dimensions:** 48.9 cm. x 48.3 cm. x 40.2 cm.
- **Mass:** 80 kg. (CPF 55 kg., Stowage 25 kg.)
- **Power:** 130 Watts continuous
- **Sample material:** Experiment specific
- **Capacity/flight:** Multiple samples/flight
- **Processing temp.:** 30° C to 60° C
- **Light Sources** 1.2 mW HeNe laser, LED with collimator

Data Acquisition
- CCD camera
- Linear CCD array
- Photo camera with exchangeable 100 exposure film pack and autodrive
- Interferometer
- Photomultiplier
- Thermal Data
- Fluid Pressure

Scheduled Flights
STS-65/Second International Microgravity Laboratory (IML-2) Mission

Development Center
European Space Agency
European Space Research and Technology Centre (ESTEC) Noordwijk, The Netherlands

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University of Amsterdam, Netherlands

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Microgravity Science & Applications Division

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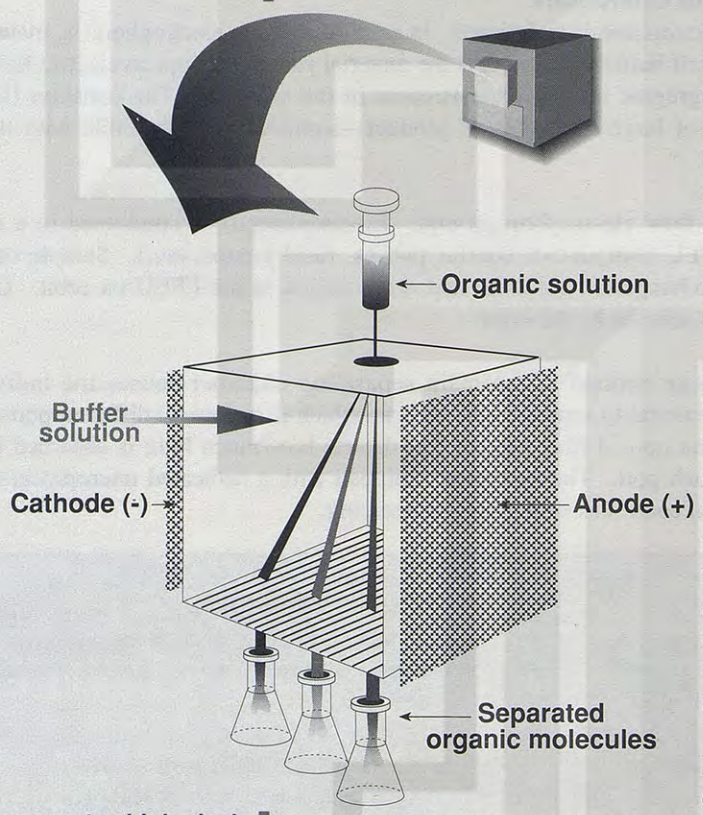
Focus

FFEU

Free Flow Electrophoresis Unit

Introduction

The Free Flow Electrophoresis Unit (FFEU) is a multi-user facility developed by the National Space Development Agency of Japan (NASDA) for the study of electrophoresis. Electrophoresis is a process for separating biological materials into individual components using an electrical field. It is widely used in the production and purification of drugs and medicines.



FFEU separates biological materials on the basis of their electrical charge and polarity.

While Earth-based electrophoresis processing provides better separation than many other processes, gravity-induced fluid movements such as convection (fluid flows caused by density differences) and sedimentation (settling of heavier components) tend to remix the components during separation. These effects are reduced in microgravity, and FFEU investigators are studying whether electrophoresis in space may improve the purity of certain organic materials which are normally difficult to separate on Earth. The FFEU has already flown successfully on the Spacelab J mission (STS-47/SL-J) in September of 1992.

Overview and Significance

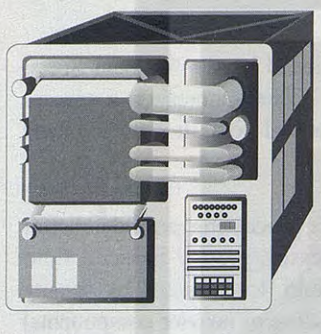
Each element and compound has a certain net electrical charge. When exposed to an electric field, a charged molecule of an element will move toward the oppositely-charged side of the field, and move away from the side with the same charge. These attractive and repulsive forces will move the molecule across the field. When numerous molecules are mixed in a fluid, the application of an electric field causes them to separate according to their charge. Eventually, all the molecules will segregate, with positively and negatively charged molecules on opposite sides.

In electrophoresis, molecules separate not only on the basis of charge polarity (positive or negative), but also according to the amount of charge present on the molecule, as well as its size. For example, a molecule that is very negative will feel greater attractive and repulsive forces than a slightly negative particle. It will move more quickly than the molecule possessing less charge. However, the larger the molecule, the more the buffer solution will resist the molecule's motion. This is the basis of the electrophoresis separation process.

On Earth, these principles remain true, but gravity introduces flows that mix and disperse components of a solution. Different molecules with nearly the same charge are affected more by incidental fluid movements than by the tug of the electric field. The tendency of these molecules to separate due to slight charge differences is overcome by the convective flows and sedimentation. Thus, gravity places limits on the purity of separated material that electrophoresis can achieve. Researchers will use the FFEU to escape these limits by taking advantage of the reduction of gravity-induced phenomena in space.

With the virtual absence of convection and sedimentation in microgravity, other important phenomena normally masked by gravity's effects come into play affecting the separation of molecules. As streams of organic material form during the separation process, there can be a buildup of charge in the organic molecules as they flow together and increase in concentration. This can cause the molecules in the stream--which all carry a similar charge--to repulse each other, suddenly breaking apart the stream. There can also be differences in the conductivity between the buffer solution and the streams, causing the

FFEU
Free Flow Electrophoresis Unit



FFEU Main Unit

latter to change shape or to "flutter." This is because the applied electric field cannot move evenly through both the buffer solution and the streams of organic material. The electric field can itself cause variations in the buffer solution, similarly disrupting the even flow of molecules. Scientists are interested in these electrohydrodynamic effects, which become more predominant in microgravity.

Experiment Hardware and Operations

There are many different electrophoresis techniques. In continuous flow electrophoresis, material is placed into a moving stream of buffer solution. As the material passes through an electric field, the individual components congregate into discrete streams in the solution. The constant flow of material allows processing of large quantities of product—something not possible with the gel method.

The FFEU is a continuous flow electrophoresis unit. Electrophoresis is conducted in a sealed chamber containing the FFEU components (buffer pumps, fluid pumps, etc.). Sample organic materials are stored in interchangeable cassettes and are installed in the FFEU on orbit. One of three buffer solutions can be selected by the crew.

An adjustable electric charge applied in the main separation chamber causes the individual components of the sample material to separate into streams which flow into 60 different ports. The process is monitored using an optical fiber system that detects how much light is absorbed by the materials passing through each port. The system is equipped with a dedicated microprocessor for operations and environmental control as well as data processing.

Carrier
Shuttle/Spacelab

Physical Characteristics
- **Dimensions:** 48.3 cm. x 53.1 cm. x 60.9 cm.
- **Mass:** 90 kg. (approx.)
- **Power:** 578 Watts (peak)
- **Sample material:** Experiment specific
- **Sample application:** 2.0 ml./cassette
- **Sample separation:** 60 ports
- **Capacity/flight:** Multiple samples/flight
- **Operating temp.:** Less than 5° C
- **Maximum electric field:** 100 Volts/cm.
- **Maximum current:** 100 mA
- **Maximum flow rate:** 25 ml./min.

Data Acquisition
- Samples returned to Earth for analysis
- Ultraviolet absorbency monitoring of separation chamber

Scheduled Flights
STS-65/Second International Microgravity Laboratory (IML-2) Mission

Development Center
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Tokyo, Japan

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Hitachi Ltd., Japan

Office of Life and Microgravity Science and Applications
Microgravity Science & Applications Division

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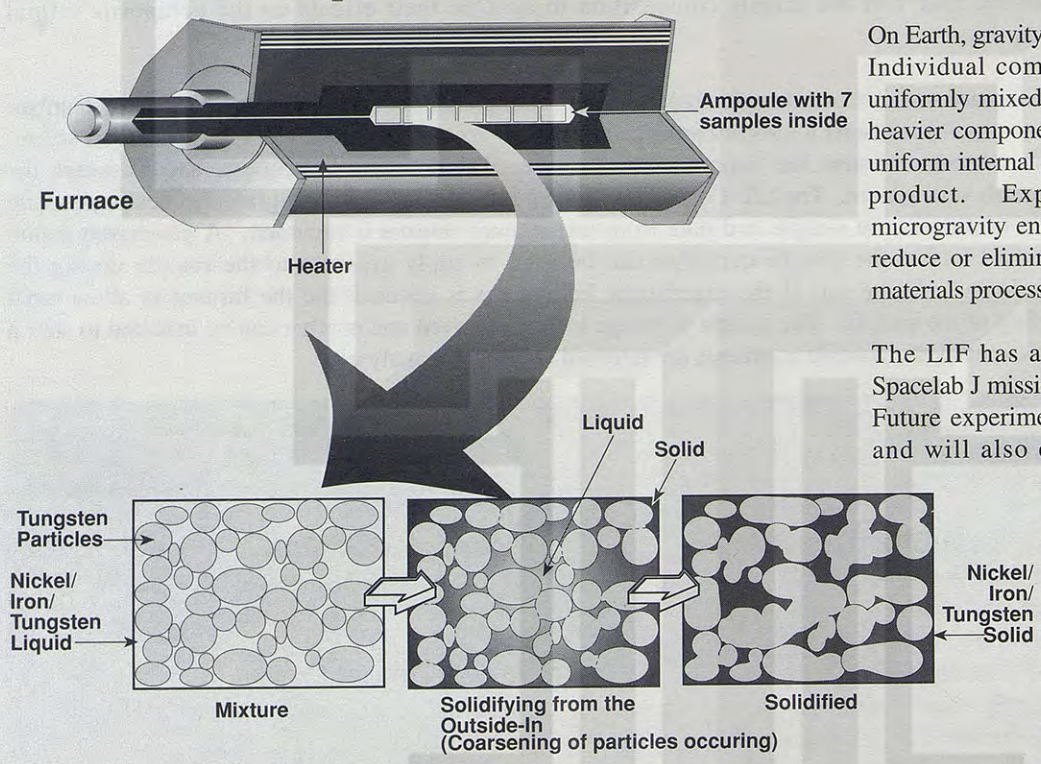
Focus

LIF

Large Isothermal Furnace

Introduction

The Large Isothermal Furnace (LIF) is a multi-user apparatus for conducting materials science research in microgravity that has been developed by the National Space Development Agency of Japan (NASDA). Materials Science researchers explore the relationships between the structure, processing, and properties of materials. One goal of materials scientists is to custom design materials to meet the demands of specific applications.



LIF will melt a Nickel/Iron/Tungsten mixture and freeze it to obtain a uniform distribution of the particles in the mixture.

On Earth, gravity can affect the processing of materials. Individual components of a material may not be uniformly mixed because of sedimentation (settling of heavier components from lighter), resulting in a non-uniform internal structure and composition in the solid product. Experiments have shown that the microgravity environment of Earth orbit can greatly reduce or eliminate some of gravity's effects during materials processing.

The LIF has already flown successfully on the Spacelab J mission (STS-47/SL-J) in September, 1992. Future experiments will elaborate on previous work and will also explore new aspects of materials processing. Knowledge gained from post-flight analysis of returned samples will help scientists to better understand and improve production techniques on Earth and to assess the feasibility of producing unique materials in space.

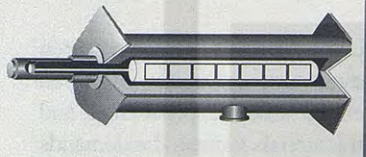
Overview and Significance

In order to create lighter, stronger, or more temperature resistant materials, metallurgists often combine two or more different metals into an alloy which has more desirable qualities than each of its ingredients. One process for combining dissimilar metals, called *sintering*, uses heat and pressure to join powdered forms of different metals without reaching the melting point of one or both metals. The powdered metals are combined and mixed to ensure an even distribution of the materials before processing. One set of materials, called composites, are combinations of very dissimilar substances. For example, metals and ceramics, or metals and carbon fibers, can combine to produce structural materials that are stronger and lighter than conventional metals.

The production of alloys and composites such as these can be difficult on Earth. The key to success is the uniform distribution of the various chemical components throughout the finished product. Because the constituent ingredients have dissimilar densities, gravity causes them to settle differently. Gravity induced movements such as sedimentation cause uneven particle distribution throughout the material, which can diminish the uniformity of its microscopic structure, distort the finished products shape, and decrease the precision of the casting process.

A microgravity environment greatly reduces buoyancy-driven convection and sedimentation, which may allow the attainment of homogenous mixtures of dissimilar materials in spite of great density differences. Scientists will use the LIF to study sintering, ceramic/metallic composites, and alloy research in the microgravity environment of space.

LIF
Large Isothermal Furnace



LIF Furnace core cutaway view showing ampoule

Experiment Hardware and Operations

The LIF is a resistance-heated vacuum furnace designed to uniformly heat large samples. It has a maximum operating temperature of 1,600° C and can rapidly cool a sample by admitting helium gas into the heating chamber. Dr. Randall German of Pennsylvania State University will take advantage of this apparatus to study the sintering of nickel iron tungsten alloys in microgravity during the Second International Microgravity Laboratory (STS-65/IML-2) in July, 1994. He will vary the sintering time and the sample composition to analyze their effects on the composite's final properties.

The furnace consists of a sample container and heating element, surrounded by a vacuum chamber. A crew member inserts a sample cartridge through an access port in the front of the LIF. A screw-type connector secures the sample in the furnace. The chamber is then evacuated through the Spacelab vent system. The LIF Control Equipment runs through a pre-programmed heating/cooling cycle to process the sample and data from temperature sensors is recorded. A gas-driven piston installed within the sample cartridge can be used to apply pressure to the sample during the experiment. At the end of the experiment, helium gas is injected into the furnace to allow rapid cooling of the sample. The sample cartridge is then removed and another can be installed to start a new experiment. Sample cartridges are returned to Earth for analysis.

Carrier
Shuttle/Spacelab

Physical Characteristics
- **Dimensions:** 44 cm. x 27 cm. x 43 cm.
- **Mass:** 36 kg
- **Power:** 420 Watts continuous (700 Watts peak)
- **Sample material:** Experiment dependent
- **Ampoule size:** 16.8cm (length) x 6cm (diam.)
- **LPS Sample size:** 10cm x 10cm x 10cm
- **Capacity/flight:** Multiple samples/flight
- **Operating temperature:** 1,600° C Max.
- **Sample temp. uniformity:** ± 1° C
- **Temperature accuracy:** ± 9° C
- **Heating rate:** < 80 minutes from room temp. to 1,600° C
- **Cooling rate:** < 420 minutes from 1,600° C to room temp.

Data Acquisition
- Temperature data from three thermocouples

Scheduled Flights
STS-65/Second International Microgravity Laboratory (IML-2) Mission

Development Center
National Space Development Agency of Japan
Tokyo, Japan

Principal Investigators
Dr. R. M. German
Pennsylvania State University, USA
Dr. A. Hirata
Waseda University, Japan
Dr. M. Takeyama
National Resource Institute for Metals, Japan

Office of Life and Microgravity Science and Applications
Microgravity Science & Applications Division

NASA—Code UG, Washington DC 20546 • FEBRUARY 1994 **STFS-013**

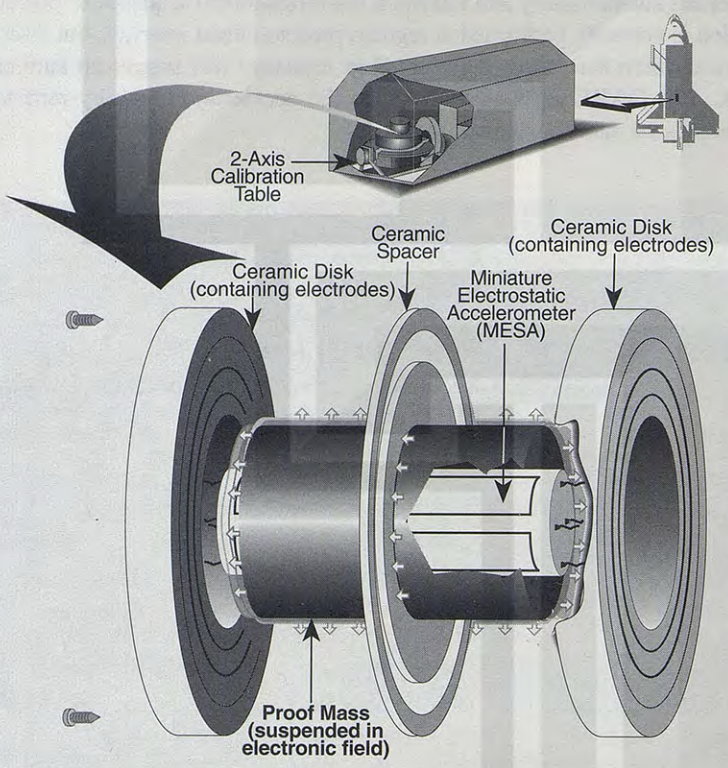
Focus

OARE

Orbital Acceleration Research Experiment

Introduction

There is no hard boundary between Earth's atmosphere and space, no line where one ends and the other begins. The planet's atmosphere is thickest at the surface and thins gradually with increasing elevation. Even the altitudes reached by the Space Shuttle are not completely devoid of air. The shuttle travels very rapidly through this tenuous, near vacuum atmosphere and is slightly slowed (decelerated) by friction from it. Also, because the density of the atmosphere changes from day to night, the amount of friction (decelerating force) varies proportionally.



OARE measures quasi-steady (low-frequency, low-magnitude) orbital accelerations.

The Orbital Acceleration Research Experiment (OARE) makes extremely accurate measurements of these variations and other disturbances with a sensor called an accelerometer. The OARE records these disturbances as small accelerations (changes in velocity) and vibrations experienced during Space Shuttle on-orbit operations. By analyzing these and other types of microgravity disturbances, researchers can assess the influence of Shuttle accelerations on scientific experiments carried onboard.

Overview and Significance

The OARE has already flown successfully on a number of Space Shuttle missions as part of the Orbiter Experiment Program (OEX). These previous missions had two objectives. The first was to provide scientists with important information regarding aerodynamic drag (friction with the atmosphere) and upper atmosphere density (thickness of the air at high altitudes). Researchers were also interested in studying the high-velocity, low-density environment (known as rarified flow aerodynamics) of low Earth orbit which the Shuttle operates in. This information is impossible to obtain on Earth, and has helped scientists better understand the upper atmosphere and aerodynamic behavior in it.

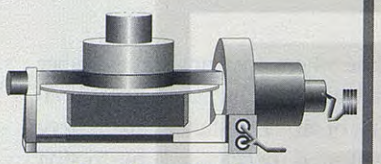
The OARE hardware is being pressed into service once again, this time to augment the ongoing study of the Space Shuttle's acceleration environment. The OARE will extend measurements currently being provided by the Space Acceleration Measurement System (SAMS). The OARE is capable of sensing and recording accelerations on the order of one billionth the acceleration of Earth's gravity (1 nano-g), at a rate of change (frequency) of less than once per second (1 Hz). These measurements will provide a more complete picture of the microgravity (low gravity) environment in the Space Shuttle. Scientists will use this information to determine how the disturbances influence experiment behavior.

Experiment Hardware and Operations

At the heart of the OARE system is the accelerometer, which has a cylindrical mass (called a proof mass) suspended within an electrostatic field—the accelerometer housing. The proof mass is pulled in different directions by static electric fields generated by the electrodes within the housing. When the fields exert an equal pull in all directions on the proof mass, it floats between them. This is known as electrostatic suspension. An acceleration in any direction will cause the proof mass to move with respect to its enclosure, distorting the suspending electrostatic field. These field distortions are proportional to the applied acceleration and are measured and interpreted by OARE's electronics.

NASA

OARE
Orbital Acceleration Research Experiment



2-axis Calibration Table

The accelerometer mounts on a movable table that allows in-flight calibration. During calibration of the accelerometer, any inherent accelerometer error is determined and can be compensated for in post-flight data analysis. The OARE's nano-g sensitivity makes it impossible to calibrate on Earth, since there is no place quiet (vibration free) enough at this level of acceleration.

Once activated, the OARE operates autonomously and follows a pre-programmed sequence of operation modes. For example, calibration is normally performed at regular, predetermined intervals, but a sensor saturation (an acceleration greater than the sensor is designed to measure) will trigger an automatic initialization and calibration. The OARE software conditions the acceleration data by removing frequencies above 1 Hz, and records the data on magnetic tape.

Carrier
Shuttle cargo bay

Physical Characteristics
- **Dimensions (LxWxH):**
  43 cm. x 105 cm. x 33 cm.
- **Mass:** 44 kg.
- **Power:** 100 Watts
- **Sensor resolution:**
  Down to 3.2 nano-g (3.2 x 10-9 g)
- **Full-scale input limits:**
  From 10,000 x 10-6 g to 1 x 10-6 g

Data Acquisition
- Simultaneous analog-to-digital (A/D) conversion of triaxial inputs, using a 16 bit A/D converter
- Recording of accelerometer data on tape
- Data downlink and control uplink capability
- Solid-state temperature sensors

Scheduled Flights
- Multiple flights

Program Office
Microgravity Science and Applications Division
NASA Headquarters
Washington, DC

Development Center
NASA Johnson Space Center
Houston, Texas

Management Center
Clifford Siegert
NASA Lewis Research Center
Cleveland, Ohio

Office of Life and Microgravity Sciences and Applications
Microgravity Science & Applications Division

NASA—Code UG, Washington DC 20546 • OCTOBER 1993 STFS-007

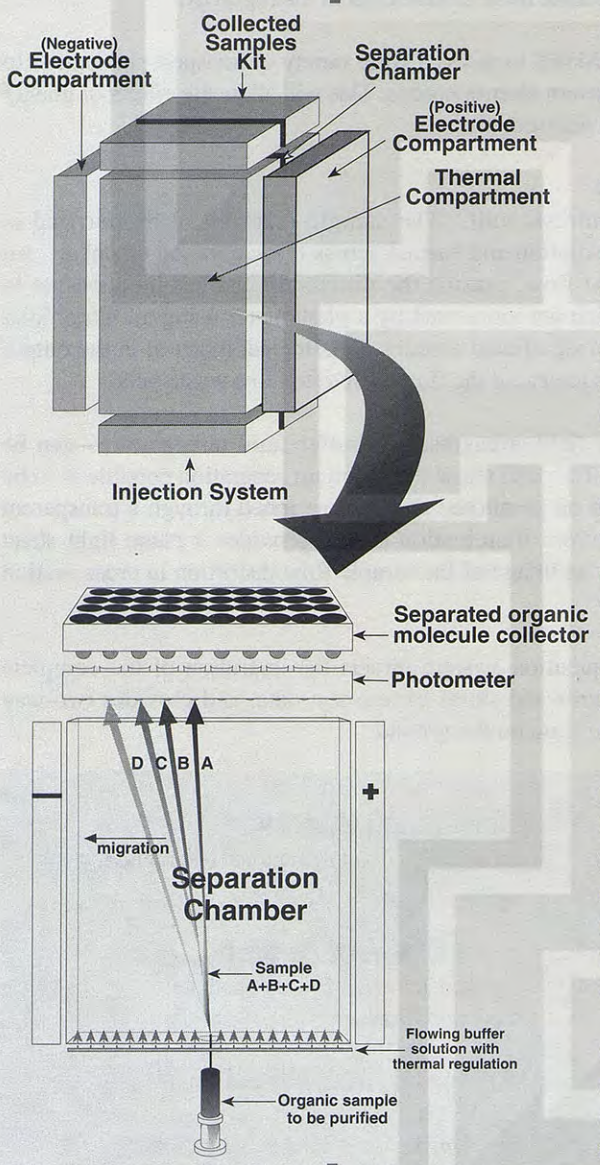
Focus

RAMSES

Recherche Appliquee Sur Les Methodes De Separation en Electrophorese Spatiale

Introduction

RAMSES (the French acronym for Applied Research on Separation Methods Using Space Electrophoresis) is a multi-user facility under development by the French Space Agency, in conjunction with European research centers and industries from France, Belgium, and Spain (within the Eureka program framework), to support basic and applied research on electrophoresis in space. Electrophoresis is a process for separating biological materials into individual components using an electrical field. It is used to purify biological materials for analysis or production of pharmaceutical drugs.



RAMSES separates biological materials on the basis of their electrical charge and polarity.

While Earth-based electrophoresis processing provides better separation than many other processes, the purity of many materials can still be improved. Gravity-induced phenomena such as sedimentation (settling of heavier components) and convection (flows within fluids caused by density differences) tend to remix the components during separation. Thus, gravity places limits on the purity and production rate that electrophoresis can achieve. RAMSES will allow researchers to study the process of electrophoresis without the effects of convection and sedimentation in the microgravity environment of space.

Overview and Significance

Depending on their environment, molecules can have net electrical charges. When exposed to an electric field, a charged molecule of an element will move toward the oppositely-charged side of the field, and move away from the side with the same charge. These attractive and repulsive forces will move the molecule across the field. When numerous molecules are mixed in a fluid, the application of an electric field causes them to separate according to their charge. Eventually, all the molecules will segregate, with positively and negatively charged molecules on opposite sides.

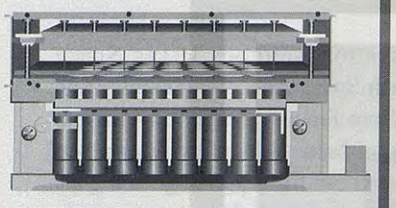
Molecules separate not only on the basis of charge polarity (positive or negative), but also according to the amount of charge present on the molecule, as well as its size. For example, a molecule that is very negative will feel greater attractive and repulsive forces than a slightly negative particle. It will move more quickly than the molecule possessing less charge. However, the larger the molecule, the more the buffer solution will resist the molecule's motion. This is the basis of the electrophoresis separation process.

On Earth, these principles remain true, but gravity introduces flows that mix and disperse components of a solution. Different molecules with nearly the same charge are affected more by incidental fluid movements than by the tug of the electric field. The tendency of these molecules to separate due to slight charge differences is overcome by the convective flows and sedimentation. Thus, gravity places limits on the purity of separated material that electrophoresis can achieve. Ramses will allow researchers to escape these limits by taking advantage of the reduction of gravity-induced phenomena in space.

With the virtual absence of convection and sedimentation in microgravity, other important phenomena normally masked by gravity's effects come into play, affecting the separation of molecules. As streams of organic material form during the separation process, there can be a buildup of charge in the organic molecules as they flow together and increase in concentration. This can cause the molecules in the stream--which all carry a similar charge--to repulse each other, suddenly breaking apart the stream. There can also be differences in the conductivity between the buffer solution and the streams, causing the

RAMSES

Recherche Appliquee Sur Les Methodes De Separation en Electrophorese Spatiale



Collection chambers

latter to change shape or to "flutter." This is because the applied electric field cannot move evenly through both the buffer solution and the streams of organic material. The electric field can itself cause variations in the buffer solution, similarly disrupting the even flow of molecules. Scientists are interested in these electrohydrodynamic effects, which become more predominant in microgravity.

Scientists will conduct experiments using RAMSES to assess a wide variety of transport phenomena to better understand the basic mechanisms that govern electrophoresis. This will allow the effects of gravity on the purification of biological products to be assessed.

Experiment Hardware and Operations

RAMSES is a continuous flow electrophoresis unit. The sample material to be purified is continuously injected into a flowing buffer solution and carried across the separation chamber. An adjustable electric field is applied across the flow, causing the differently charged components to deflect into separate streams (fractions) which are monitored by a photometer using an ultra-violet light source. When the photometer detects a significant amount of biological material in the output flow, each stream is individually collected. Otherwise the flow is diverted to a waste tank.

Separation parameters—flow rates, electric field strengths, and buffer fluid temperature—can be altered to study a wide range of conditions. This will allow the optimum separation conditions to be determined. Separation experiments can also be monitored and photographed through a transparent window in the instrument front panel. A cross illumination source provides a plane light sheet across the separation chamber that produces an image of the sample flow distortion in cross section when viewed from the correct angle.

The RAMSES Control Command and Acquisition System directs the operation of the complete system. It provides the user interface, acquires and stores experiment data, and provides two-way data and control connections with the science team on the ground.

Carrier

Shuttle/Spacelab

Physical Characteristics

- **Dimensions:** 200 cm. x 60.2 cm. x 44.7 cm.
- **Mass:** 220 kg.
- **Power:** < 500 Watts
- **Sample material:** Experiment specific
- **Sample separation:** 40 output ports
- **Sample capacity:** 10 - 15 ml.
- **Capacity/flight:** Multiple samples/flight
- **Maximum electric field:** 65 Volts/cm.
- **Maximum current:** 100 mA for 0-150V; 50 mA for 150-300V

Data Acquisition

- Samples returned to Earth for analysis
- Protein concentration monitored by UV absorption measurement

Scheduled Flights

STS-65 Second International Microgravity Laboratory (IML-2) Mission

Development Center

Centre National d'Etudes Spatiales
Toulouse, France

Principal Investigators

Dr. V. Sanchez
University of Paul Sabatier, France
Dr. R. Snyder
NASA, Marshall Space Flight Center, USA

Office of Life and Microgravity Science and Applications
Microgravity Science & Applications Division

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Illustrations: L. Palting

Focus

SAMS

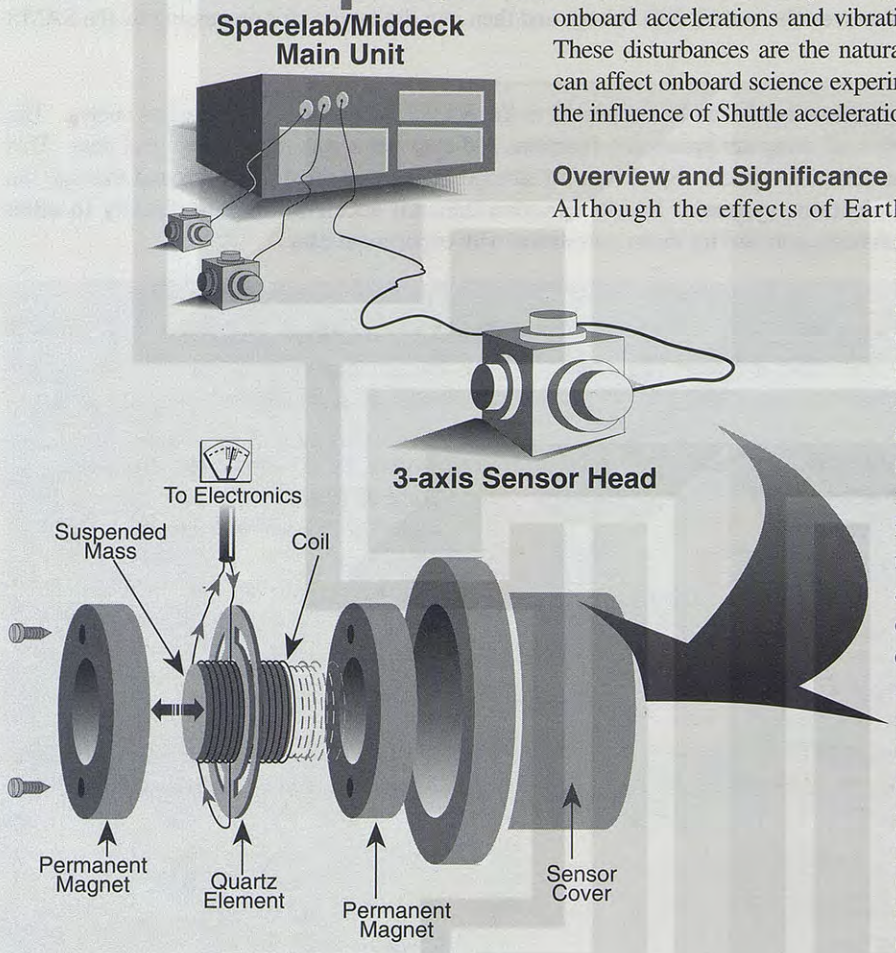
Space Acceleration Measurement System

Introduction

The Space Acceleration Measurement System (SAMS) is an instrument that monitors and records onboard accelerations and vibrations experienced during Space Shuttle orbital flight. These disturbances are the natural results of Shuttle operations and activity, but they can affect onboard science experiments. Researchers will use the SAMS data to assess the influence of Shuttle accelerations on their experiments.

Overview and Significance

Although the effects of Earth's gravity are significantly reduced in orbit, disturbances are not completely eliminated. Shuttle maneuvers, equipment operations, atmospheric drag, and even crew movements can create disturbances. These residual accelerations and vibrations can affect sensitive microgravity investigations taking place onboard. SAMS makes accurate measurements of these disturbances with sensors called accelerometers, and records the data for later analysis. During flight, acceleration data is also transmitted to scientists on the ground for near-real-time processing and science support. By analyzing microgravity disturbances, scientists can determine how these disturbances influence experiment results. All flight data is analyzed following the flight to characterize the acceleration environment inside the Shuttle. This baseline description of the Shuttle acceleration environment will assist experiment developers in preparing for future flights. Scientists are particularly interested in measurements made during specific Shuttle maneuvers, periods of intense crew activity such as exercise, and operations using the Shuttle's robot arm.



Accelerometer

SAMS (Space Acceleration Measurement System) is an instrument that monitors and records on-board accelerations and vibrations experienced throughout a Space Shuttle flight.

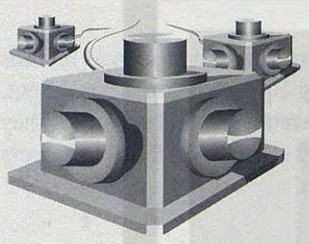
Experiment Hardware and Operations

There are two distinct types of SAMS: the Spacelab/middeck version and the cargo bay version. The Spacelab/middeck SAMS is crew accessible and designed to operate in the pressurized environment of the Shuttle cabin or Spacelab. It is controlled by the crew and has no downlink or uplink capability. The extreme thermal fluctuations and mechanical stress associated with exposure to space dictate a more robust design for the cargo bay SAMS. It has a specially designed protective enclosure and mounting system for attachment to the Mission Peculiar Equipment Support Structure (MPESS) in the cargo bay. The cargo bay SAMS is controlled via data link with the ground. The crew can also command SAMS from the Shuttle flight deck.

The SAMS Cargo bay version has three main components: the control unit, the data storage unit, and the remote sensor heads. The sensor heads can be positioned on the MPESS carrier or inside individual experiments. Each SAMS sensor head consists of three single-axis acceleration sensors oriented at right angles to each other. This allows the sensor head to detect accelerations in three dimensions.

Each accelerometer consists of a mass suspended by a quartz element in such a manner as to allow movement along one axis only. A coil is attached to the mass and the assembly is placed in a magnetic

SAMS
Space Acceleration Measurement System



Triaxial Sensor Heads

field. An applied acceleration displaces the mass from its rest position which alters the magnetic field and causes current to flow in an electrical circuit. The current is proportional to the applied acceleration. SAMS electronics convert the current into voltage and then into digital data for processing by the SAMS computer.

Up to three remote sensor heads can be connected to the SAMS control unit via electrical cables. The control unit performs all computer processing functions and converts sensor signals to digital data. This information is transferred to optical disk drives for storage or is transmitted to the ground through the Shuttle's communications systems. SAMS can also transmit acceleration data directly to other microgravity experiments onboard for direct correlation with experiment data.

Carrier
Orbiter middeck, Spacelab, or Mission Peculiar Experiment Support Structure (MPESS)

Physical Characteristics
- **Spacelab/middeck version**
  - Dimensions (LxWxH): 45 cm. x 26 cm. x 53 cm.
  - Mass: 30 kg
  - Power: 60 Watts (average)
- **Cargo bay version**
  - Dimensions (LxWxH): 100 cm. x 75 cm. x 75 cm.
  - Mass: 100 kg
  - Power: 110 Watts (average)
- **System resolution:** ±0.5g to 15µg
- **Triaxial sensor heads:** 3 heads/system
  - Sensor Resolution: 1 µG
- **Data capacity**
  - cargo bay, 800 megabytes
  - Spacelab/Middeck, unlimited

Data Acquisition
- Simultaneous analog-to-digital (A/D) conversion of triaxial inputs, using a 16 bit A/D converter
- Recording up to 500 samples/sec. from each accelerometer sensor
- Data downlink and control uplink capability (cargo bay version)
- Solid-state temperature sensors

Scheduled Flights
- Multiple flights per year

Program Office
Microgravity Science and Applications Division
NASA Headquarters
Washington, DC

Development Center
NASA Lewis Research Center
Cleveland, Ohio

Project Manager (acting)
Clifford Siegert
NASA Lewis Research Center
Cleveland, Ohio

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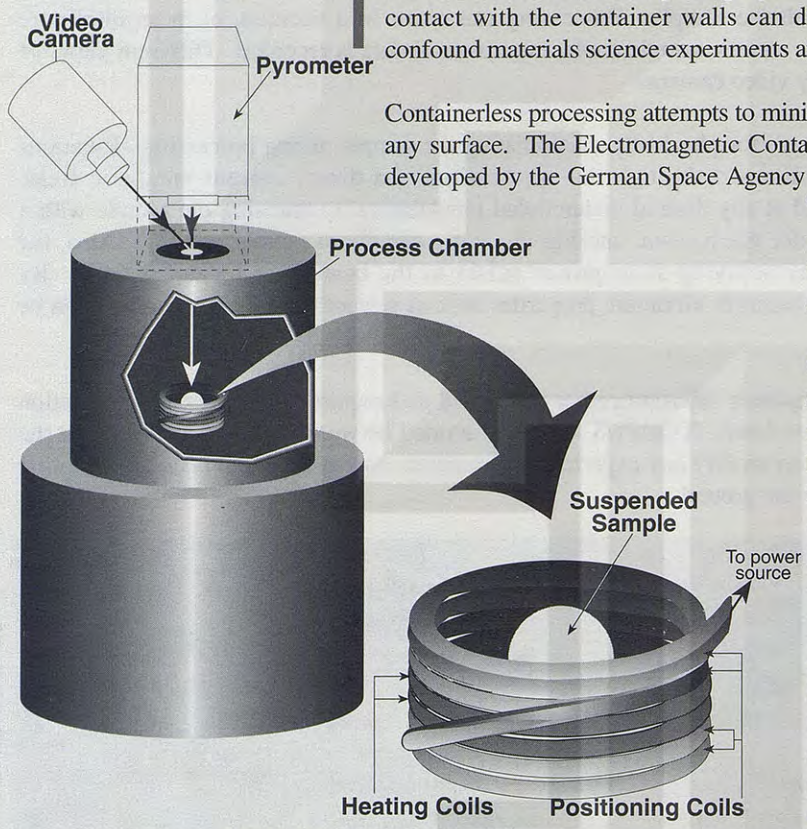
Office of Life and Microgravity Sciences and Applications
Microgravity Science & Applications Division

Focus

TEMPUS

Electromagnetic Containerless Processing Facility



TEMPUS electromagnetically levitates samples so they can be melted without contamination from container walls.

Introduction

The freezing or solidification of materials from the liquid state is of immense scientific and practical interest. Not only are solidification phenomena fundamentally important to science, but many industrial processes involve solidification. On Earth, liquids generally must be held in containers, and these containers can affect the liquid's properties. For example, a container determines a liquid's shape, and contact with the container walls can diminish its purity. These container-sample interactions can confound materials science experiments and limit the results of materials processing.

Containerless processing attempts to minimize such effects by levitating the sample to avoid contact with any surface. The Electromagnetic Containerless Processing Facility (TEMPUS) is a multi-user facility developed by the German Space Agency to allow containerless processing of materials in microgravity. TEMPUS provides a unique environment that researchers can use to test fundamental theories of materials properties. This basic research will help scientists better understand material solidification, and may improve production methods on Earth.

Overview and Significance

Crystalline solidification begins when small, isolated clusters of atoms arrange in a regular, repeating form. This process is known as nucleation, and the clusters are called nuclei. Atoms fall into place on the nuclei causing the sites to grow until the entire mass becomes solid. Nucleation occurs easily at solid to liquid boundaries, such as the boundary between solid container walls and the liquid sample it holds.

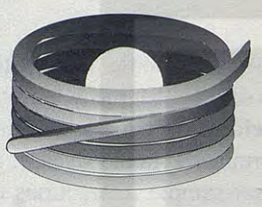
A liquid can be cooled to below its freezing point and still remain fluid (undercooling). The temperature to which a material can be undercooled depends, among other things, on its purity and the physical properties of its container. A smooth container offers fewer nucleation sites than a rough one, thus allowing a greater degree of undercooling. The container can also affect the microscopic structure of the resulting solid. Many nucleation sites offered by the large contact area of a sample and its container can cause solidification to begin in many places at once. The resulting solid will appear as a patchwork of many small crystals as opposed to fewer, larger crystals produced by fewer nucleation sites.

TEMPUS seeks to minimize these complications by electromagnetically levitating the sample. TEMPUS uses an electric current flowing through coils of copper tubes to produce magnetic fields. These fields induce electric currents within an electrically conductive sample. The induced currents, in turn, produce their own magnetic fields that interact with the coil's fields. By carefully forming the coils, it is possible to create an area of minimum field strength in which the sample will levitate (float).

On Earth, levitation is impractical for all but the smallest samples due to the high field strengths required to counteract the downward pull of gravity. In addition, sample heating caused by high power levels produce fluid movements within the sample and place a limit on the lowest temperature to which the sample can be subjected. The microgravity environment of space drastically lowers power requirements as the specimen floats practically without weight. The coils are used mainly to maintain sample position. The resulting reduced sample heating and diminished fluid motion are less intrusive on the phenomena being examined.

TEMPUS

Electromagnetic Containerless Processing Facility



Heating and positioning coils levitating a sample

Experiment Hardware and Operations

Twenty-two spherical specimens, each up to ten millimeters in diameter, can be accommodated on a storage disk within the TEMPUS unit. The disk rotates until the desired specimen is positioned over a transfer mechanism. The mechanism unlocks the sample holder and transfers the sample to the processing area within the levitation coils. Once levitated by the positioning coils, a separate heating coil is used to melt the sample. Processing can occur in a vacuum, or in an ultra-pure Helium/Argon atmosphere. As the sample cools, experimental data is recorded. Different views of the process are recorded by video cameras.

TEMPUS provides the means for physically manipulating the sample during processing. Rotations and oscillations can be damped through the application of a direct current magnetic field. Nucleation can be initiated at any desired undercooled temperature by touching the sample with a needle driven by the transfer mechanism, causing the entire sample to rapidly solidify. Also, the sample can be vibrated by applying short power pulses to the heating or levitation coils. By observing how the sample reacts to vibration, properties such as surface tension and viscosity can be inferred.

Operations are almost completely microprocessor-controlled and require very little crew interaction other than start up and shut down. TEMPUS is reprogrammed between each experiment from the ground. It is also possible to modify any experiment parameters during sample processing by either the crew on board, or from the ground.

Carrier

Shuttle/Spacelab

Physical Characteristics

- **Dimensions:** One Spacelab rack
- **Mass:** 194 kg
- **Power:** 2400 Watts peak
- **Sample material:** Experiment specific
- **Capacity/flight:** up to 22 samples/flight
- **Sample diameter:** 6 to 10 cm
- **Processing temperature:** up to 2400° C

Data Acquisition

- Process chamber vacuum or gas pressure
- Real time and recorded CCD video images
- Facility housekeeping data

Scheduled Flights

STS-65/Second International Microgravity Laboratory (IML-2) Mission

Development Center

German Aerospace (DARA)
Bonn, Germany

Principal Investigators

Dr. R. Bayuzick
Vanderbilt University, USA
Dr. M. Flemings,
Massachusetts Institute of Technology, USA
Dr. D. M. Herlach
DLR, Institut für Raumsimulation, Germany
Dr. W. L. Johnson
California Institute of Technology, USA
Dr. J. Szekely
Massachusetts Institute of Technology, USA
Dr. K. Urban
Juelich Science Center, Germany

Office of Life and Microgravity Science and Applications
Microgravity Science & Applications Division

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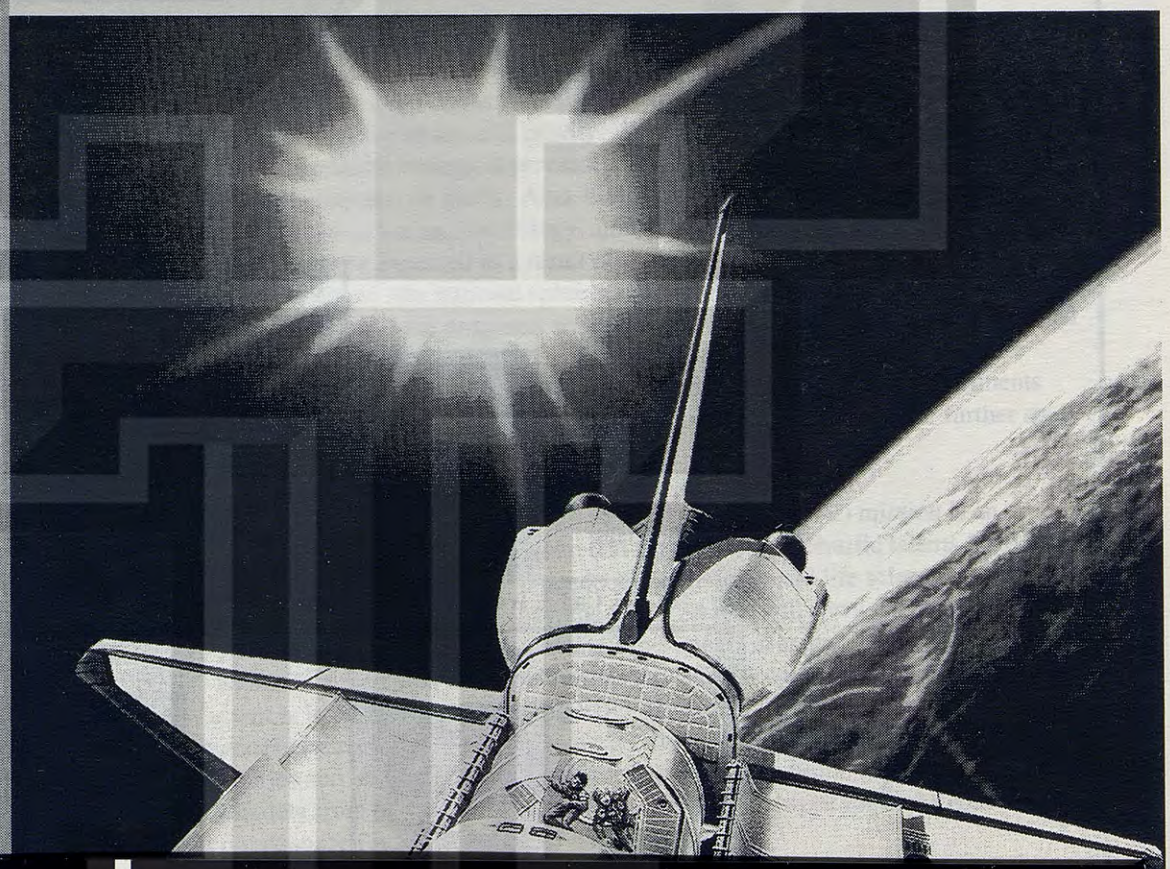
Illustrations: L. Palting

FOCUS

International Microgravity Laboratory 2

LIFE SCIENCES



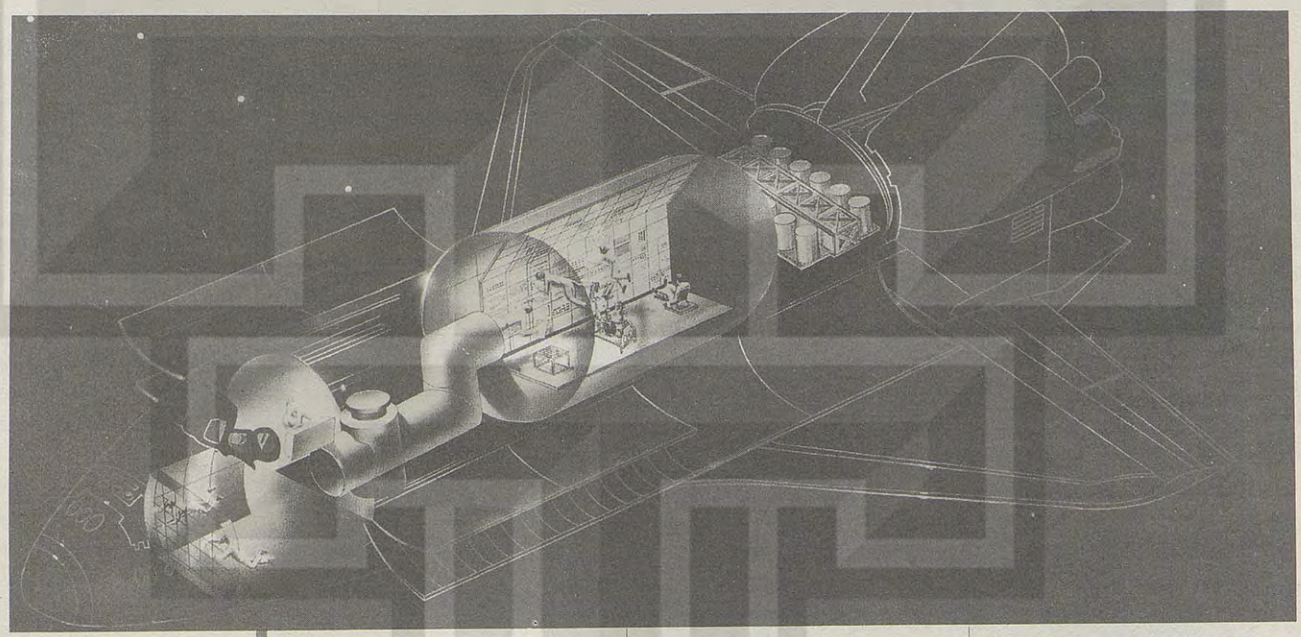
IML-2/IML2

NASA HQ (Washington DC): Mission Statement

As part of its mandate to guide the United States' civil space program, the National Aeronautics and Space Administration (NASA) is committed to preserving U.S. preeminence in critical aspects of space science, applications, and technology. The Office of Life and Microgravity Sciences and Applications (OLMSA) is responsible for planning and executing the basic and applied research activity associated with the Microgravity Science and Applications Program.

Microgravity Science & Applications Division

The Second International Microgravity Laboratory (IML-2)



THE SECOND INTERNATIONAL MICROGRAVITY LABORATORY (IML-2)

The Second International Micro-

expenses. IML-2 also will provide a preview of science operations and flight hardware on the International Space Station.

The first IML mission flew in January of 1992, successfully completing eleven U.S. micro-

growth of electronic materials, solidification of metal model alloys, and critical point fluid physics. The IML-2 payload consists of 78 major experiments; of these, eleven are sponsored by the Microgravity Science and Applications Division (MSAD) and

Microgravity Science and Applications Program

NASA's Microgravity Science and Applications Program is responsible for establishing goals for the OLMSA mission in the microgravity research areas of biotechnology, combustion, fluid physics, materials science, and benchmark experiments. The Microgravity Science and Applications Division sponsors scientific research using low gravity and other attributes of the space environment as experimental parameters.

NASA
National Aeronautics and
Space Administration