NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SPACE SHUTTLE MISSION STS-65

PRESS KIT
JULY 1994

INTERNATIONAL MICROGRAVITY LABORATORY-2 (IML-2)

STS-65 INSIGNIA

STS065-S-001 -- Designed by the crew members, the STS-65 insignia features the International Microgravity Laboratory (IML-2) mission and its Spacelab module which will fly aboard the space shuttle Columbia. IML-2 is reflected in the emblem by two gold stars shooting toward the heavens behind the IML lettering. The space shuttle Columbia is depicted orbiting the logo and reaching off into space, with Spacelab on an international quest for a better understanding of the effects of space flight on materials processing and life sciences.

The NASA insignia design for space shuttle flights is reserved for use by the astronauts and for other official use as the NASA Administrator may authorize. Public availability has been approved only in the form of illustrations by the various news media. When and if there is any change in this policy, which we do not anticipate, it will be publicly announced.

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RELEASE: 94-96

INTERNATIONAL MICROGRAVITY LABORATORY MAKES SECOND FLIGHT

Shuttle Mission STS-65 will see Space Shuttle Columbia and her seven-person crew conduct the second flight of the International Microgravity Laboratory-2 (IML-2), a payload that involves a world-wide research effort into the behavior of materials and life in the weightless environment of Earth- orbit.

The STS-65 crew will use furnaces and other facilities to produce a variety of material structures, from crystals to metal alloys. From the experiments conducted, scientists will be able to examine subtle forces which affect material development in microgravity. Investigators also will be able to study fluid processes that are masked or distorted on Earth. This knowledge may help us develop the next generation of materials needed for high-tech applications and lead to refinement of materials such as semiconductors, superconductors, and exotic ceramics and glasses.

The life science experiments conducted during IML-2 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. The reduced gravity encountered in space allows certain characteristics of cells and organisms to be studied using innovative laboratory hardware and techniques. Insights scientists gain about life in space can increase knowledge of the factors which govern life and health on Earth.

Scientists from NASA, the European Space Agency (ESA), the French Space Agency (CNES), the German Space Agency (DARA), the Canadian Space Agency (CSA) and the National Space Development Agency of Japan (NASDA) have cooperated in planning experiments which will be performed during the STS-65 mission. More than 200 scientists developed over 80 investigations for the IML-2 mission.

Leading the STS-65 crew will be Mission Commander Robert D. Cabana who will be making his third flight. Pilot for the mission is James Donald Halsell Jr. who is making his first flight. The four mission specialists aboard Columbia are Richard J. Hieb, the STS-65 Payload Commander, who will be making his third flight; Carl E. Walz who will be making his second flight; Leroy Chiao, who will be making his first flight; and Donald A. Thomas who will be making his first flight. Chiaki Naito-Mukai from the National Space Development Agency of Japan will serve as a payload specialist for the STS- 65 mission and will be making her first flight.

Launch of Columbia currently is scheduled for no earlier than July 8, 1994, at 1:11 p.m. EDT. The planned mission duration is 13 days, 17 hours, 56 minutes. An on-time launch on July 8 would produce a landing at 7:07 a.m. EDT on July 22, 1994, at the Kennedy Space Center’s Shuttle Landing Facility.

The Commercial Protein Crystal Growth payload, sponsored by the Office of Advanced Concepts and Technology (OACT), will be making its fifth flight on STS-65, using the Commercial Refrigerator/Incubator Module (CRIM) in the Shuttle middeck. This complement of experiments contains 60 different samples focusing on six proteins in various formulations to enhance the probabilities for successful results.

Two Department of Defense-sponsored experiments will be flown during the STS-65 mission. The Air Force Maui Optical System (AMOS) is an electrical-optical facility on the Hawaiian island of Maui. The AMOS facility tracks the orbiter as it flies over the area and records signatures from thruster firings, water dumps or the phenomena of “shuttle glow.” The information obtained by AMOS is used to calibrate the infrared and optical sensors at the facility. The Military Applications of Ship Tracks (MAST) experiment on STS-65 is part of a five- year research program to examine the effects of ships on the marine environment. The objective of MAST is to determine how pollutants generated by ships modify the reflective properties of clouds. MAST will help in understanding the effects of man- made aerosols on clouds and the resulting impact on the climate system.

The STS-65 crew will take on the role of teacher as they educate students in the United States and other countries about STS-65 mission objectives. Using the Shuttle Amateur Radio Experiment-II (SAREX-II), astronauts aboard Columbia will discuss with students what it is like to live and work in space.

STS-65 will be the 17th flight of Space Shuttle Columbia and the 63rd flight of the Space Shuttle system.

(END OF GENERAL RELEASE; BACKGROUND INFORMATION FOLLOWS.)

STS-65 MEDIA SERVICES INFORMATION

NASA Television Transmission

NASA television is now available through a new satellite system. NASA programming can now be accessed on Spacenet-2, Transponder 5, located at 69 degrees west longitude; frequency 3880.0 MHz, audio 6.8 MHz.

The schedule for television transmissions from the orbiter and for mission briefings will be available during the mission at Kennedy Space Center, Fla; Marshall Space Flight Center, Huntsville, Ala.; Dryden Flight Research Center, Edwards, Calif.; Johnson Space Center, Houston and NASA Headquarters, Washington, D.C. The television schedule will be updated to reflect changes dictated by mission operations.

Television schedules also may be obtained by calling COMSTOR 713/483-5817. COMSTOR is a computer data base service requiring the use of a telephone modem. A voice update of the television schedule is provided daily at noon EDT.

Status Reports

Status reports on countdown and mission progress, on- orbit activities and landing operations will be produced by the appropriate NASA news center.

Briefings

A mission press briefing schedule will be issued prior to launch. During the mission, status briefings by a Flight Director or Mission Operations representative, and when appropriate, representatives from the payload team, will occur at least once per day. The updated NASA television schedule will indicate when mission briefings are planned.

STS-65 QUICK LOOK

Launch Date/Site:	July 8, 1994/Kennedy Space Center - Pad 39A
Launch Time:	1:11 p.m. EDT
Orbiter:	Columbia (OV-102) - 17th Flight
Orbit/Inclination:	160 nautical miles/28.45 degrees
Mission Duration:	13 days, 17 hours, 56 minutes
Landing Time/Date:	7:07 a.m. EDT July 22, 1994
Primary Landing Site:	Kennedy Space Center, Fla.
Abort Landing Sites:	Return to Launch Site - KSC, Fla. TransAtlantic Abort Landing: - Banjul, The Gambia Ben Guerir, Morocco Moron, Spain Abort Once Around: - Edwards Air Force Base, Calif.
STS-65 Crew:	Robert Cabana, Commander (CDR) Jim Halsell, Pilot (PLT) Rick Hieb, Payload Commander (MS1) Carl Walz, Mission Specialist 2 (MS2) Leroy Chiao, Mission Specialist 3 (MS3) Don Thomas, Mission Specialist 4 (MS4) Chiaki Mukai, Payload Specialist 1 (PS1) Red shift: Cabana, Halsell, Hieb, Mukai Blue shift: Chiao, Thomas, Walz
Cargo Bay Payloads:	International Microgravity Lab-2 (IML-2)
Middeck Payloads:	Commercial Protein Crystal Growth (CPCG) Shuttle Amateur Radio Experiment-II (SAREX-II) Orbiter Acceleration Research Experiment (OARE) Military Applications of Ship Tracks (MAST)
Other:	Air Force Maui Optical Site (AMOS)

Detailed Test Objectives/Detailed Supplementary Objectives:

DTO 251	Entry Aerodynamic Control Surfaces Test
DTO 301D	Ascent Structural Capability Evaluation
DTO 307D	Entry Structural Capability Evaluation
DTO 312	External Tank Thermal Protection System Performance
DTO 319D	Orbiter/Payload Acceleration and Acoustics Environment Data
DTO 414	Auxiliary Power Unit Shutdown Test
DTO 623	Cabin Air Monitoring
DTO 655	Foot Restraint Evaluation
DTO 663	Acoustic Noise Dosimeter Data
DTO 665	Acoustic Noise Sound Level Data
DTO 667	Portable In-Flight Landing Operations Trainer
DTO 674	Thermo-Electric Liquid Cooling System Evaluation
DTO 805	Crosswind Landing Performance
DTO 913	Microgravity Measurement Device
DSO 314	Acceleration Data Collection
DSO 326	Window Impact Observations
DSO 484	Assessment of Circadian Shifting in Astronauts by Bright Light
DSO 485	Inter Mars TEPC
DSO 487	Immunological Assessment of Crewmembers
DSO 491	Characterization of Microbial Transfer Among Crewmembers During Space Flight
DSO 603B	Orthostatic Function During Entry, Landing and Egress
DSO 604	Visual-Vestibular Integration as a Function of Adaptation
DSO 605	Postural Equilibrium Control During Landing/Egress
DSO 608	Effects of Space Flight on Aerobic and Anaerobic Metabolism During Exercise
DSO 610	In-Flight Assessment of Renal Stone Risk
DSO 614	The Effect of Prolonged Space Flight on Head and Gaze Stability During Locomotion
DSO 621	In-Flight Use of Florinef to Improve Orthostatic Intolerance Postflight
DSO 626	Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight
DSO 901	Documentary Television
DSO 902	Documentary Motion Picture Photography
DSO 903	Documentary Still Photography

SPACE SHUTTLE ABORT MODES

Space Shuttle launch abort philosophy aims toward safe and intact recovery of the flight crew, Orbiter and its payload. Abort modes include:

- Abort-To-Orbit (ATO) -- Partial loss of main engine thrust late enough to permit reaching a minimal 105-nautical mile orbit with orbital maneuvering system engines.

- Abort-Once-Around (AOA) -- Earlier main engine shutdown with the capability to allow one orbit around before landing at Edwards Air Force Base, Calif.

- TransAtlantic Abort Landing (TAL) -- Loss of one or more main engines midway through powered flight would force a landing at either Banjul, The Gambia; Ben Guerir, Morocco; or Moron, Spain.

- Return-To-Launch-Site (RTLS) -- Early shutdown of one or more engines, and without enough energy to reach Banjul, would result in a pitch around and thrust back toward KSC until within gliding distance of the Shuttle Landing Facility.

STS-65 contingency landing sites are the Kennedy Space Center, Edwards Air Force Base, Banjul, Ben Guerir and Moron.

STS-65 Summary Timeline

Flight Day 1
Ascent
OMS-2 burn (163 n.m. x 160 n.m.)
IML-2 activation/operations

Blue Flight Days 2-13
IML-2 operations

Red Flight Days 2-14
IML-2 operations

Blue Flight Day 14
IML-2 operations

Red Flight Day 14
Flight Control Systems Checkout
Lower Body Negative Pressure Device

Blue/Red Flight Day 15
Cabin stow
Payload deactivation
IML-2 deactivation
Deorbit
Entry
Landing

STS-65 VEHICLE AND PAYLOAD WEIGHTS

	Pounds
Orbiter (Columbia) empty and 3 SSMEs	181,443
International Microgravity Lab-2	21,187
Commercial Protein Crystal Growth	58
Orbiter Acceleration Research Experiment	249
Shuttle Amateur Radio Experiment-II	37
Military Applications of Ship Tracks	66
Detailed Supplementary/Test Objectives	205
Total Vehicle at SRB Ignition	4,522,321
Orbiter Landing Weight	228,640

STS-65 ORBITAL EVENTS SUMMARY

Event	Start Time (dd/hh:mm:ss)	Velocity Change (feet per second)	Orbit (n.m.)
OMS-2	00/00:42:00	221 fps	163 x 160
Deorbit	13/16:56:00	270 fps	N/A
Touchdown	13/17:56:00	N/A	N/A

STS-65 CREW RESPONSIBILITIES

Task/Payload	Primary	Backups/Others
Middeck Payloads:		
SAREX	Cabana	Thomas
CPCG	Cabana	Walz
MAST	Walz	Cabana
OARE	Thomas	Walz, Halsell
Detailed Test Objectives:		
DTO 312	Thomas	Chiao
DTO 414	Halsell	Walz
DTO 623	Walz	Halsell
DTO 655	Chiao	Hieb
DTO 663	Cabana	Walz
DTO 665	Cabana	Walz
DTO 667	Cabana	Halsell
DTO 805	Cabana	Halsell
Detailed Supplementary Objectives:		
DSO 314	Halsell	Walz
DSO 485	Cabana	Walz
Other:		
Photography/TV	Halsell	Walz
In-Flight Maintenance	Walz	Halsell
EVA	Chiao (EVA1)	Thomas (EV2), Walz (IV)
Earth Observations	Halsell	Cabana
Medical	Cabana	Walz

IML -2 PAYLOADS: CREW ASSIGNMENTS

Payload	Primary	Backups/Others
AAEU	Thomas	Mukai, Chiao, Hieb
APCF	Chiao	Hieb, Thomas, Mukai
BDPU	Thomas	Mukai, Chiao, Hieb
Biorack	Chiao	Hieb, Thomas, Mukai
CPF	Chiao	Hieb, Thomas, Mukai, Cabana
EDOMP	Mukai	Hieb, Thomas, Chiao
FFEU	Mukai	Thomas, Hieb, Chiao
LIF	Mukai	Thomas, Hieb, Chiao
NIZEMI	Chiao	Hieb, Thomas, Mukai
PAWS	Cabana	Halsell, Walz
QSAM	Thomas	Mukai, Chiao, Hieb
RAMSES	Thomas	Mukai, Chiao, Hieb
RRMD	Mukai	Thomas, Hieb, Chiao
SAMS	Thomas	Mukai, Chiao, Hieb
SCM	Hieb	Mukai
TEI/CCK	Mukai	Thomas, Hieb, Chiao
TEMPUS	Thomas	Mukai, Chiao, Hieb

IML-2: THE SECOND INTERNATIONAL MICROGRAVITY LABORATORY

The second International Microgravity Laboratory Spacelab mission brings together scientists from around the world in a search for answers which might only be found in the unique laboratory of space.

As the Shuttle orbits Earth, it provides a nearly weightless, or microgravity, environment. Microgravity cannot be duplicated for longer than a few seconds with Earth-based facilities. The IML-2 mission objective is to conduct microgravity and life sciences research that can only be accomplished in this low-gravity environment.

In a space laboratory, some of the physical processes which affect experiments on Earth are not as dominant. Gravity-related disturbances such as buoyancy, sedimentation and hydrostatic pressure cannot only limit the quality of some materials but also limit the ways materials can be studied.

IML-2 scientists will use furnaces and other facilities to produce a variety of material structures, from crystals to metal alloys. They will examine subtle forces which affect material development in microgravity. Scientists also will be able to study fluid processes that are masked or distorted on Earth. Nearly every physical science depends on an understanding of these basic mechanisms. This knowledge may help us develop the next generation of materials needed for high-tech applications and lead to refinement of materials such as semiconductors, superconductors, and exotic ceramics and glasses.

Life science research on IML-2 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 can make space our second home, we must understand how living things are affected by reduced gravity and radiation in the space environment. Insights scientists gain about life in space can increase knowledge of the factors which govern life and health on Earth.

For instance, previous space flights have demonstrated that high quality protein crystals, suitable for X-ray analysis, can be grown in space. If the structures of certain proteins can be determined by examining these crystals, not only will we learn about an essential component of all life forms, but we could use this knowledge to improve the medical treatment of many diseases.

IML-2 Science

More than 200 scientists from six space agencies developed over 80 investigations for the IML-2 mission. Representatives of the European Space Agency (ESA), the French Space Agency (CNES), the German Space Agency (DARA), the Canadian Space Agency (CSA) and the National Space Development Agency of Japan (NASDA) are joining NASA in this mission of discovery.

An international crew will conduct these experiments inside Spacelab, a versatile research laboratory which fits in the Space Shuttle cargo bay. It is an appropriate place for multi-national research, since Spacelab was developed by the ESA in the late 1970s and early 1980s as its contribution to the American Space Shuttle Program. IML-2 uses the pressurized Spacelab module. With its extra work area, power supplies, data management capability and versatile equipment racks, scientists in space can work much as they would in their laboratories on Earth.

Many IML-2 experiments owe their heritage to earlier Skylab, sounding rocket and ground-based experiments. Some have evolved over several Spacelab missions. Facilities flown on previous flights are being flown again to probe new scientific questions or to expand on prior studies. This mission also will introduce some new experiment facilities, designed to give scientists additional tools for finding answers in the microgravity of space.

MATERIALS SCIENCE: NASDA's **Large Isothermal Furnace** melts and uniformly mixes compounds, then cools them to produce a solid sample. The **Electromagnetic Containerless Processing Facility** from Germany positions metal alloys so they do not touch container walls and melts them in an ultra-pure environment. The facility records information on the alloys as they solidify.

FLUID SCIENCE: The European Space Agency's **Bubble, Drop and Particle Unit** contains special optical diagnostics, cameras and sensors for studying fluid behavior in microgravity. Their **Critical Point Facility**, which flew on IML-1, investigates fluids as they undergo critical phase transitions from liquids to gases.

MICROGRAVITY ENVIRONMENT AND COUNTERMEASURE: **NASA's Space Acceleration Measurement System**, on its tenth flight, will be joined on IML-2 by the German Space **Agency's Quasi-Steady Acceleration Measurement** experiment. Together, they will give scientists the most complete picture yet of the subtle motions which can disturb sensitive microgravity experiments. Japan's **Vibration Isolation Box Experiment System** will test a special material designed to reduce the effect of those accelerations.

BIOPROCESSING: ESA's **Advanced Protein Crystallization Facility** will provide a versatile environment for growing a variety of protein crystals using three different techniques. A video recording device will allow scientists to study the crystal growth process after the mission. Two experiment facilities, **Applied Research on Separation Methods Using Space Electrophoresis** from France and the Free Flow Electrophoresis Unit from Japan, will use electric fields to separate biological materials into their individual components. The process is widely used on Earth to produce ultra-pure products for pharmaceutical drugs.

SPACE BIOLOGY: Two space biology facilities from the 1992 Japanese Spacelab-J mission will fly on IML-2. Scientists will study the spawning, fertilization, embryology and behavior of newts and fish housed in the **Aquatic Animal Experiment Unit**. The **Thermoelectric Incubator/Cell Culture Kit** will accommodate the study of plant and animal cells. IML-2 will be the third flight for the European Space Agency's **Biorack**, which supports investigations into the effects of microgravity and cosmic radiation on cells, tissues, plants, bacteria, small animals and other biological samples. **The Slow Rotating Centrifuge Microscope** from Germany contains equipment for observing the movement and behavior of one-celled and multi-cellular organisms at various gravity levels. Materials scientists will take advantage of its capabilities to observe the solidification of a transparent model alloy as well.

HUMAN PHYSIOLOGY: Canada's **Spinal Changes in Microgravity** experiment, an expanded version of an IML-1 investigation, will use stereophotographs and special ultrasound and monitoring equipment to record changes in crew members' spinal and neurosensory systems. **NASA's Extended Duration Orbiter Medical Project** will continue investigations designed to maintain and evaluate crew health and safety on long-duration Shuttle flights. The crew will use the **Performance Assessment Workstation**, a laptop computer, to help determine their mental ability to perform operational tasks during long-duration missions.

RADIATION BIOLOGY: Germany's **Biostack**, a veteran of three Spacelab missions, sandwiches biological specimens between radiation detectors in a sealed container to determine how cosmic radiation affects them. Japan's **Real-Time Radiation Monitoring Device** will test methods which may be used for space radiation forecasting aboard future spacecraft.

Mission Operations

The Marshall Space Flight Center in Huntsville, Ala., manages IML-2 for NASA's Office of Life and Microgravity Science and Applications, Washington, D.C. Experiment operations for the 14-day flight will be directed from the agency's Spacelab Mission Operations Control facility at Marshall.

During the mission, hundreds of scientists and engineers representing the many IML-2 experiments will work in the Science Operations Area. From there, they can monitor experiments via video and voice links with the Shuttle, send remote commands to their instruments, discuss operations with the crew in space, and coordinate mission activities with their colleagues from other experiment teams. The ESA experiment teams will be backed up by colleagues working at remote sites in Amsterdam, The Netherlands; Brussels, Belgium; Naples, Italy; Toulouse, France; and Cologne, Germany. Additional science teams will be located at the Johnson Space Center and the Kennedy Space Center.

Primary responsibility for operating the experiments in orbit belongs to the Spacelab science crew. Payload Commander Rick Hieb, Mission Specialists Leroy Chiao and Don Thomas, and Payload Specialist Chiaki Mukai will work in two 12-hour shifts. Operating the Spacelab 24 hours a day enables scientists to get the most from valuable time in orbit. The crew will work from a preplanned master timeline, with adjustments made for unexpected opportunities.

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

The investigators will be rewarded with new insights into the intrinsic properties of materials, increased knowledge about how gravity affects living systems on Earth, and no doubt new questions to be answered in the unique laboratory of space.

Large Isothermal Furnace

Payload Developer: NASDA

Objective: The Large Isothermal Furnace uniformly heats large materials samples in a vacuum, then cools them rapidly to determine the relationships between the structure, processing and properties of materials. On IML-2, scientists will solidify five samples under various temperature conditions, studying ceramic/metallic composites, semiconductor alloys, and liquid phase sintering. Sintering is a process for combining dissimilar metals, using heat and pressure to join them without reaching the melting point of one or both metals.

Significance: Knowledge gained from post-flight sample analysis will help scientists better understand and improve production techniques on Earth. They also will use the results to assess the feasibility of producing unique materials in space.

Science: 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. Or they may combine dissimilar substances such as metals and ceramics to produce structural materials that are stronger and lighter than conventional metals.

The key to success is the uniform distribution of the various chemical components throughout the finished product. On Earth, gravity causes ingredients with dissimilar densities to settle differently as heavier components are pulled downward. This gravity-induced movement, called sedimentation, causes uneven

particle distribution throughout the material. It can diminish the uniformity of its microscopic structure, distort the finished product's shape, and decrease the precision of the casting process.

A microgravity environment greatly reduces buoyancy- driven convection and sedimentation. This may allow the uniform mixture of dissimilar materials in spite of great density differences.

Experiment Hardware and Operations: The facility is a resistance-heated vacuum furnace designed to uniformly heat large samples. It has a maximum operating temperature of about 2,900 degrees Fahrenheit (1,600 !C) and can rapidly cool a sample by admitting helium gas into the heating chamber.

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 facility. A screw-type connector secures the sample in the furnace. Air within the chamber is evacuated through the Spacelab vent system.

The furnace control equipment runs through a pre- programmed heating/cooling cycle to process the sample, and data from temperature sensors are recorded. A gas-driven piston 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 cartridge is then removed and another can be installed to start a new experiment. Sample cartridges are returned to Earth for analysis.

Background: The Large Isothermal Furnace was developed by the National Space Development Agency of Japan (NASDA). It flew on the Spacelab-J mission in September 1992. Eight samples were processed successfully during that flight and are being analyzed by investigators.

Gravitational Role in Liquid Phase Sintering

Experiment Facility: Large Isothermal Furnace
Principal Investigator:
Dr. Randall M. German
Pennsylvania State University
University Park, Pa.

Objective: This experiment will determine how gravity changes heavy alloys of tungsten, nickel and iron during sintering, a process for combining dissimilar metals. Sintering uses heat and pressure to join powdered forms of different metals without both components.

The material will be heated so the iron and nickel form a liquid, surrounding the uniformly dispersed powdered tungsten. Samples will be analyzed post-flight to investigate both macrostructural changes, such as those in shape and texture, and microstructural changes, including density and high-temperature strength.

Significance: Liquid phase sintering is a process used to produce alloys of novel compositions. For example, due to density differences between the tungsten and the iron-nickel liquid that forms at high temperatures, sintering is the only process by which this alloy can be fabricated. This IML-2 investigation will add to ground-based research, which indicates that gravity plays a role in distorting the microstructure of samples sintered on Earth. Tungsten heavy alloys were chosen for this experiment because of widespread interest in the alloy system, extensive sintering experience on Earth, a large database on properties, and approximately a factor of two density difference between the liquid and solid phases.
Background: Five different compositions of tungsten-nickel alloy were sintered at 2,730 degrees Fahrenheit (1,500 degrees C) in the Large Isothermal Furnace during the Spacelab-J mission. One sample set was sintered for 60 minutes, and another was sintered for 300 minutes. Samples with larger percentages

of nickel tended to behave like liquids. Since they were not distorted by gravity as they would have been on Earth, they solidified into spherical shapes. Scientists concluded that the mixture of liquid and small solid particles behaves like liquid in microgravity, regardless of density differences in the materials, when a continuous liquid layer is formed at the surface.

Operations: A crew member will load a sample cartridge containing seven different compositions of tungsten heavy alloy into the Large Isothermal Furnace, then activate a preprogrammed, computer-controlled processing sequence. The cartridge will be rapidly heated to 2,730 degrees Fahrenheit (1,500 degrees C) for a little over an hour, gradually cooled with water for almost another hour, then rapidly cooled by a continuous flow of helium for about 3-1/2 hours more. The astronaut then will remove the cartridge and stow it for return to Earth.

The procedure will be repeated with two more cartridges. Sintering time and sample composition will be varied to identify their effects on final properties of the composites.

The samples, as well as thermal and acceleration data collected during the experiment, will be analyzed post-flight.

Mixing of a Melt of Multicomponent Compound Semiconductor

Experiment Facility: Large Isothermal Furnace
Principal Investigator:
Dr. Akira Hirata
Waseda University
Tokyo, Japan

Objective: This investigation will develop a new method for uniformly mixing melted compound semiconductors. It will test whether the components can be mixed faster and more uniformly using Marangoni convection, that is, fluid flows driven by the concentration differences on the surface of a liquid.

Science: Semiconductors are made of several constituents with different densities. On Earth, gravity separates the components, as heavier materials settle from lighter ones. In space, without any mixing devices, it may be possible to mix these components more uniformly and faster using Marangoni convection, a type of fluid flow driven by differences in surface tension. Although these flows exist on Earth, they are masked by the much stronger forces of sedimentation and buoyancy-driven convection, caused by density differences within the liquid.

Surface tension is the force which causes falling water to form into drops. In space, away from gravity's distortion, it forms an uncontained liquid into a perfect sphere. Previous space experiments have demonstrated that variations in the temperature on the free surface of a fluid create predictable flow patterns within that fluid. Investigators for this experiment will test whether this gentle flow is a useful tool for uniformly mixing semiconductor components.

Significance: Semiconductors are materials whose conductivity is poor at low temperatures, but is improved by application of heat, light or voltage. They are widely used in computers and other electronic devices to transmit electrons in a controlled manner. A better mixture would result in a semiconductor with more uniform content, allowing it to transmit electrons more efficiently.

Operations: Two different compounds of indium-gallium-antimony (InGaSb) will be melted and solidified in the Large Isothermal Furnace to form semiconductors. The experiment cartridge will contain a total of six samples.

Four samples will be processed using Marangoni convection to mix the components. As a material cools and contracts, a void is left in the sample ampoule. Material next to the void forms a free surface which does not touch the sides of the ampoule, allowing Marangoni convection to occur.

Two samples will be processed using only molecular diffusion to mix the components. The void created by cooling and contraction, and the resulting free surface will be eliminated by a gas-driven piston within the cartridge. It will automatically move forward to take up the empty space as the sample material contracts.

The solidified crystals will be compared postflight to determine crystal quality, crystal shape, and size of crystal particulates. Scientists also will compare the effects of the two processing methods on mixing of the melted components and the uniformity of the solidified semiconductor.

Background: Dr. Masami Tatsumi grew an indium-gallium-arsenide crystal in the Spacelab-J Gradient Heating Furnace. A piston was used to prevent Marangoni convection within that experiment. The resulting mixture was more uniform than that of a comparison crystal grown on Earth, but it was not completely homogeneous.

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

Experiment Facility: Large Isothermal Furnace
Principal Investigator:
Dr. Masao Takeyama
National Research Institute of Metals
Tokyo, Japan

Objective: This experiment will melt and resolidify a titanium-aluminum alloy to which ceramic particles of titanium diboride have been added. The particles should increase the high-temperature strength of the material, improving the microstructure and thus the mechanical properties of the alloy.

Science: Ceramic particles must be evenly distributed within an alloy to improve grain structure and mechanical properties. On Earth, differences in density between the particles and the alloy prevent uniform distribution, because gravity pulls the heavier particles downward. In microgravity, the uneven distribution caused by density differences should be prevented. Heat convection, which also affects solidification, should be minimal.

Significance: Results should help investigators understand some of the principal influences that occur during this type of material processing. Insights gained about microstructural control could be applied to producing more effective materials on Earth. This technology for controlling alloy microstructure may be applied to improve high-temperature alloys needed for high-tech aircraft and spacecraft.

Operations: A crew member will place a cartridge containing four titanium-aluminum samples, each 18 mm in diameter and 25 mm long, in the Large Isothermal Furnace. Two of the samples will have ceramic particles added; the others will not. They will be heated to approximately 2820 degrees Fahrenheit (1550 degrees C), then solidified in microgravity.

This is planned to be the last sample cartridge processed in the furnace during IML-2, and it will remain in the facility until after landing. Post flight, scientists will study the effect of the resulting microstructure on mechanical properties such as strength. In addition to the two flight samples being compared with one another, they will be compared with those processed on the ground.

Electromagnetic Containerless Processing Facility
Tiegelfreies Elektromagnetisches Prozessieren UnterSchwerelosigkeit
(TEMPUS)

Payload Developer: German Space Agency (DARA)

Objective: To study the solidification of materials from the liquid state, a subject of immense scientific and practical interest. Not only are solidification phenomena important to science, but many industrial processes involve solidification.

On Earth, liquids generally must be held in containers, which can affect the liquid's properties. For example, a container determines a liquid's shape, and contact with the container walls can diminish the purity of the metal sample.

In microgravity, samples can be processed in a containerless facility, which avoids contact with any surface. The Electromagnetic Containerless Processing Facility, known as TEMPUS, is a levitation melting facility for containerless processing of metallic samples in an ultraclean microgravity environment. It was developed by the German Space Agency.

Science: In the absence of a container, most pure molten metals can be cooled to below their solidification point and still remain fluid. 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 these clusters causing the sites to grow until the entire mass becomes solid.

Nucleation occurs at solid to liquid boundaries, such as the boundary between solid container walls and the liquid sample it holds. The container walls, consisting of arranged atoms, act as the nuclei site. The resulting solid will appear as a patchwork of many small crystals as opposed to fewer, larger crystals produced by fewer nucleation sites in microgravity. It is this undercooling phenomenon that scientists are interested in studying.

Background: This is the maiden flight for the TEMPUS facility. The 22 samples accommodated by the facility are being shared by many of the principal investigators so as to gather the maximum scientific data from the limited number of alloy samples available. Therefore, as a general rule, each sample is of interest to more than one principal investigator.

Hardware: The TEMPUS system uses an electric current flowing through coils of copper tubes to produce magnetic fields. By carefully forming the coils, it is possible to create an area of minimum field strength in which the sample will levitate or float.

On Earth, lifting a sample in apparent defiance of gravity requires a very powerful electromagnetic force. Not only does this deform the sample and agitate the melted alloy, but independent temperature control is impossible. In microgravity, positioning of the sample and temperature control can be accomplished accurately and precisely because the power necessary for positioning the sample is greatly reduced. The reduced amount of current results in diminished fluid motion which is less intrusive on the phenomena being examined.

The 22 spherical specimens, each up to 0.4 inch (10 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. Processing can occur in a vacuum, or in an ultra-pure helium/argon atmosphere. As the sample cools, experimental data are recorded. Different views of the process are recorded by video cameras.

The TEMPUS system provides the means for physically manipulating the sample during processing. Rotations and oscillations can be controlled 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: Experiment procedures are almost completely microprocessor-controlled and require very little crew interaction other than start up and shut down. The TEMPUS unit is reprogrammed between each experiment from the ground. The crew on board, or ground controllers, can modify any experiment parameters during sample processing.

The team of investigators will study various thermodynamic and kinetic properties of 22 samples. The metallic samples have melting points between 1634 and 3362 degrees Fahrenheit (890 and 1850 degrees C) when heated in the TEMPUS unit.

Effects of Nucleation by Containerless Processing in Low Gravity

Experiment Facility: TEMPUS
Principal Investigator:
Robert J. Bayuzick
Vanderbilt University
Nashville, Tenn.

Objective: This experiment has a two-fold purpose: - to better understand specific details of how metals solidify, and - to investigate ways in which the solidification process can be controlled.

An extensive series of experiment runs will be conducted to provide comparative data for determining the time and temperature at which a metal begins to turn into a solid. Scientists hope to pinpoint what phenomenon “kicks-off” the solidification process. The series will be conducted in the Electromagnetic Containerless Processing Facility or TEMPUS.

On Earth, the electromagnetic force necessary to levitate the sample so that it floats in apparent defiance of gravity, is so powerful that it deforms and agitates the molten metal sample. Also, levitation techniques in a 1-g environment result in large liquid flows, or convection currents, within the sample. In microgravity, the amount of electromagnetic forces required is reduced, thus causing less disturbance and stress to the free-floating, spherical sample. This containerless environment will allow the molten metal to nucleate and grow a crystal without being influenced by a container’s molecular structure.

Science: Pure liquid metals can remain in a liquid state below the point at which they should solidify. This process is called undercooling. In this experiment, scientists will try to keep the metal in a molten state for as long as possible, at the lowest possible temperature.

The condition when an undercooled liquid first begins to solidify is called nucleation. A cluster of atoms acts as a nucleation site, or foundation, for the crystal to build upon. Free-moving atoms attach themselves to this site, growing into a solid crystal structure. Scientists hope to determine the nucleation properties for the element zirconium, a strong, ductile metallic element used chiefly in ceramic and refractory compounds as an alloying agent. The nucleation properties are what characterize the molten liquid’s random movement of atoms into an ordered pattern as a solid metal. Scientists want to study this process under the condition of a high degree of undercooling.

Significance: Solidifying metals is one of the most important processes in industry. Learning more about the basic nucleation phenomena may provide clues for making different materials. The nucleation phenomenon is the most basic process governing the solidification of metals.

Background: This experiment has been performed on Earth using drop tubes that simulate low gravity for a few seconds. However, the precise measurement of temperature is difficult because during freefall the specimen is moving with respect to the detectors.

Operations: A spherical sample of zirconium about three- eighths of an inch (8 to 10 mm) in diameter will be levitated, heated to 3542 degrees Fahrenheit (1950 degrees Celsius), melted and then cooled about 300 degrees below the normal solidification point when nucleation is expected to take place. The experiment will consist of approximately 100 melting, cooling, nucleation and solidification cycles. The series will take place over four hours. Each time the sample is melted and resolidified, the nucleation temperature and rate of crystal growth will be recorded for comparison with Earth-based results to further the understanding of nucleation phenomena.

Non-Equilibrium Solidification of Largely Undercooled Melts

Experiment Facility: TEMPUS
Principal Investigator:
Dr. Dieter M. Herlach
DLR Institute for Space Simulation
Cologne, Germany

Objective: This experiment has a two-fold objective. First, it will investigate dendritic and eutectic solidification velocity resulting from undercooling. These measurements can be used to test and refine dendritic and eutectic solidification theories. Second, this investigation will study the nucleation of metastable phases below an alloy's normal solidification temperature.

Science: Dendrites -- from the Greek word for "tree" -- are tiny branching structures that form inside molten metal alloys when they solidify during manufacturing. The size, shape and structure of the dendrites have a major effect on the strength, ductility and usefulness of an alloy.

A eutectic substance -- also from a Greek word ("well-melting") -- is a material that has a melting point lower than that of any of its components. This property makes it an important material, one whose microstructure has a strong impact on mechanical, electrical and magnetic properties. An example of the eutectic phenomenon is putting salt onto ice. The salt-water mixture lowers the melting point, causing the ice to melt.

Nucleation is the starting point for solidification. The tiniest possible crystal, which scientists call an embryo, sets the solidification process into motion. If the atomic arrangement within the embryo differs from that in the usual stable solid, a metastable crystalline phase forms.

The atoms of these metastable crystals have different structural arrangements that change the alloy's properties, such as improving mechanical elasticity and strength. Coal is an example of a material produced at the normal solidification temperature. It is the stable, solid form of carbon. When the atomic structure solidifies at specific conditions, a diamond is created. Diamond is the metastable solid form of carbon. This means that in thousands of years a diamond will eventually turn into a piece of coal, the material's more stable form. When nucleation occurs at other temperatures below the normal solidification point, other materials can be created. Coal and diamond are just two of many possibilities, all dependent on the conditions at which nucleation occurs.

Significance: There are two reasons why these experiments are performed in microgravity. First, crystal growth can be strongly affected by convective fluid flow in the molten metal. The low acceleration environment in space effectively eliminates convection. Comparing space experiment data with Earth experiment data is the only practical way to separate the effects of convection from the underlying mechanism of crystal growth. On the other hand, the experiment conditions such as containerless processing of melts in an ultraclean environment promise a substantial extension of the degree of undercooling that can be achieved. It is at these very low undercooling temperatures that scientists hope to observe the nucleation of various metastable phases.

Operations: Two methods will be used to study these phenomena in the containerless environment provided within the TEMPUS facility. First, iron-nickel, nickel-carbon and nickel-silicon will be heated to 100 degrees above their melting point. Then they will be allowed to cool as far into the undercooling range as possible, until nucleation spontaneously occurs, and many independent, separate dendrites grow. The solidification velocity will be measured once nucleation occurs.

The second method will use a needle to terminate the undercooling phase. The needle will provide a nucleation site, inducing solidification at a specific temperature below the normal solidification point. Investigators will carefully control where and when dendrites begin to grow inside the experiment sample.

Several different time profiles at various temperatures will be obtained for each sample. The microstructure of the materials will be analyzed post flight, along with temperature, pressure and acceleration data.

Alloy Undercooling Experiments

Experiment Facility: TEMPUS
Principal Investigator:
Dr. Merton C. Flemings
Massachusetts Institute of Technology
Cambridge, Mass.

Objective: Atoms in a molten liquid alloy line up in a specified order as the alloy cools and becomes a solid crystal. Scientists hope to learn more about the order in which atoms attach to each other as they grow into a crystal structure. They also want to study the speed at which the crystallization process occurs.

Science: Liquid alloys allowed to solidify slowly at their natural freezing point repeatedly form what is called an equilibrium atomic structure. Atoms are consistently ordered in an identical pattern. When the solidification process is changed, the atomic structure is affected. Molten liquids that are undercooled below the point where they usually become a solid crystallize faster than when they solidify at their normal freezing point. The particles are frozen rapidly right where they are, in a matter of milliseconds. This quick cooling creates metastable solid phases that are not considered “normal” or stable. Scientists hope their results reveal how the fast-frozen solids are different and if the metal alloy’s characteristics are improved. It is possible the alloy will be stronger.
The metal’s properties are expected to change because undercooling allows the scientist to “supersaturate” the nickel-tin alloy. Tin makes up a small percentage of the initial alloy sample. However, when the alloy is supersaturated, a higher concentration of the sample is comprised of tin. This should alter the metal’s properties.

Significance: Scientists and engineers will study the experiment results to determine how the properties of metals change in an unstable fast-frozen, supersaturated state. This may help industry make better metals. For example, in the casting of high-performance metal components like jet engine turbine blades, each blade is the result of a crystal grown from a single nucleation site. Improving this process may make possible turbine blades that would have greater operating efficiency if the blades can be constructed of a metal capable of withstanding higher temperatures.

Operations: Three alloy samples will be levitated, melted and solidified in the Electromagnetic Containerless Processing Facility, nicknamed TEMPUS. Two nickel-tin spheres, one containing 25 percent tin and one almost one-third tin, will be tested and a third sample, of pure nickel, will be processed for a control experiment.

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

Experiment Facility: TEMPUS
Principal Investigator:
Dr. Knut Urban
Institute for Solid State Physics Research Center Julich
Julich, Germany

Objective: This experiment studies a unique feature of some metallic alloys - the presence of structural elements based on atom arrangements with 20 triangular sides, a shape called icosahedral. These multi-sided structures are a fairly recent discovery known as quasicrystals.

Science: Quasicrystals are so small they are called nano- crystals. Scientists are not even sure they can be considered true crystals. Because they are multi-sided -- having the icosahedral shape -- they are unstable building blocks. Therefore, they are distributed in small pockets throughout some metal alloys. As an analogy, children's building blocks - - squares, triangles and rectangles -- fit together in repetitive patterns forming a sturdy, solid structure. However, icosahedral shapes cannot tightly fit together, leaving empty spaces that weaken a building arrangement such as a crystal structure.

This investigation also is interested in the undercooling phenomena of these quasicrystals. Using the TEMPUS facility, metallic alloys can be cooled well below their melting temperature without solidification.

The quasicrystalline state in metallic alloys was discovered in 1984 as the third state of solid matter. The other two are 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. Small pockets of quasicrystals are located throughout the alloy.

Significance: This experiment contributes not only to the understanding of why and how these new quasicrystals form, but also to our knowledge about the structure of molten alloys. Scientists hope to gain insight into how atoms cluster together and eventually grow into a crystal, a process called nucleation.

Operations: Spherical samples of aluminum-copper-cobalt and aluminum-copper-iron about three-eighths of an inch in diameter (8 to 10 mm) will be levitated, melted and solidified at different temperatures using the TEMPUS. The samples will be analyzed post flight and the temperature, pressure and acceleration data recorded during the STS-65 flight, will be studied.

Thermodynamics and Glass Formation in Undercooled Liquid Alloys

Experiment Facility: TEMPUS
Principal Investigator:
Dr. Hans J. Fecht
Technical University-Berlin
Berlin, Germany

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

Experiment Facility: TEMPUS
Principal Investigator:
Dr. William L. Johnson
California Institute of Technology
Pasadena, Calif.

The objective and significance of Dr. Johnson's, as well as Dr. Fecht's investigations, are quite similar. The experimenters share their data and results, which is why they also can be described together. Dr. Fecht's experiment uses three alloys: zirconium-iron, zirconium-cobalt and zirconium- nickel. Dr. Johnson's alloys are zirconium-nickel and niobium- nickel.

Objective: This experiment uses a new mathematical method, termed the AC method, to calculate heat capacity, an important physical characteristic of metallic alloys cooled to temperatures below the point when they would normally solidify. While the formula has been evolving over several years, this will be the first time it has been used to determine heat capacity. This is possible because pure molten alloys can remain liquid at cooler-than-normal temperatures when they are suspended in a containerless processing environment such as that provided by the TEMPUS facility.

Science: A key point in understanding the physics of this experiment is that undercooled metals can remain molten many degrees below the temperature at which they normally start to form a solid crystal. At these reduced temperatures, areas with a glass-like quality can form in zirconium-based alloys. While these are not transparent, they are referred to as glass because the atoms are arranged in a similar pattern as glass used for windowpanes. The angles at which atoms are joined is not regular; in fact, the atomic structure has no long-range order at all.

As short, repetitive bursts of heat are rapidly applied to the alloy sample, its temperature will correspondingly rise and fall. This temperature increase or decrease lags slightly behind the influx of heat, which is modulated through the metal in a wavelike fashion. The time difference between the addition or subtraction of heat and the resulting temperature fluctuations is directly related to the alloy's heat capacity, defined as the amount of heat required to increase the temperature of 1 gram of material by 1 degree Celsius. Scientists will use specially designed computer software to determine the heat capacity from this temperature lag.

Significance: Understanding the fundamentals of undercooling and formation of metallic glasses is vital for designing such materials. They may find applications in many technological areas because of their unique 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 future, these injection-molded, bulk metallic glasses could influence the state of materials science and engineering.

Operations: The pure metal samples and the alloys will be levitated and heated above their melting point and then allowed to cool until they solidify. These experiments involve a series of melting-solidification.

Viscosity and Surface Tension of Undercooled Melts

Experiment Facility: TEMPUS
Principal Investigator:
Dr. Ivan Egry
DLR Institute for Space Simulation
Cologne, Germany

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

Experiment Facility: TEMPUS
Principal Investigator:
Dr. Julian Szekely
Massachusetts Institute of Technology
Cambridge, Mass.

The experiments of Drs. Egry and Szekely show the same area of specialization and follow identical procedures. Therefore only one description is necessary to explain the background and the goal of these experiments. Dr. Egry uses samples of the system gold-nickel; Dr. Szekely uses gold-copper samples.

Objective: The aim is to gain a better understanding of microscopic interactions within molten metals, such as gold, in the unusual condition of undercooling. This experiment specifically focuses on studying viscosity and surface tension characteristics. Such measurements on undercooled metals have never before been possible. On the ground, gravity distorts the molten sample, making it difficult to determine what is taking place at the atomic level.

Science: The study of viscosity and the measurement of surface tension have to do with microscopic interactions within molten metals. Materials that have high viscosity are thick and flow slowly, such as molasses and 50-weight oil as compared to 10- weight oil. Materials with low viscosity are thin and flow readily, such as water. A droplet made up of gold atoms has an even lower viscosity and therefore is expected to take a long time returning to a stable, non-oscillating sphere.

Surface tension is the force acting in the surface of a liquid -- similar to a membrane -- that causes a quantity of liquid to try to minimize its total surface area. For example, it causes a drop to be spherical, in the absence of gravity.

When a liquid drop is levitated and its normally spherical shape is disturbed, it will return to a sphere through a series of oscillations. The surface tension may be deduced from the frequency of the oscillations. Viscosity can be determined from the rate at which these oscillations slow down to a stable spherical shape.

Significance: Understanding the underlying principles governing thermophysical properties of liquid metals, in particular, viscosity and surface tension, is a matter of high scientific interest and of benefit to industries, such as electronics and manufacturing.

Knowledge of the viscosity of melts below the temperature at which they solidify will make an important contribution to the study of fluid dynamics of undercooled liquid metals. The growing field of electromagnetic processing of materials, especially the area of electromagnetic shaping of electrically conducting fluids, will benefit from this research.

Operations: This experiment will levitate and heat a gold- copper alloy sample and a pure copper sample. Then the heating unit will be switched off, and the liquid metal will be cooled below its melting point. At predetermined temperatures, the sample will be squeezed by pulsing the heating coils, thus producing

oscillations in the sample. When the squeezing force is switched off, scientists on the ground will monitor the frequency and rate of decay of the oscillations until the metal sample becomes stable and stops oscillating.

Free Flow Electrophoresis Unit (FFEU)

Payload Developer: NASDA

Objective: The Free-Flow Electrophoresis Unit is being used to study whether space-based electrophoresis will improve the purity of certain biological materials which are normally difficult to separate on Earth. Electrophoresis is a process that separates biological materials into individual components using electric fields. The method is widely used with gel matrix in the DNA sequence analysis and clinical diagnosis.

Significance: Widely used Earth-based electrophoresis is run in a gel matrix providing better separation, but limited for only small molecules. Matrix free free-flow electrophoresis, however, tends to remix the components during separation. 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. This prevents the production of suitable quantities of very pure substances. In space, however, with gravity no longer a dominant factor, these effects are minimal.

In space, other physical processes affecting the separation of molecules, which are masked by gravity on Earth, become more apparent. Scientists are interested in how these effects might influence future space-based electrophoresis. They also can use what they learn to better understand electrophoresis processes on Earth.

Science: Particles of any element or compound have an electrical charge. When exposed to an electric field, a charged molecule of an element will move toward the side of the field with the opposite charge. Eventually, all the molecules within a fluid will segregate according to their charge.

Molecules separate not only according to whether they are positively or negatively charged, but also according to the strength of the charge and the size of the molecule. Molecules with greater positive or negative charges move more quickly than those with less charge. Movement of larger molecules is slowed by increased resistance from the solution in which they are suspended.

During electrophoresis separation on Earth, gravity introduces flows which mix and disperse components of a solution. For molecules with nearly the same charge, the fluid movement is a more powerful influence than the tug of the electric field. Microgravity virtually eliminates these flows, making possible more thorough separation and thus more pure materials.

Background: This facility is furnished by the National Space Development Agency of Japan. Along with the Thermoelectric Incubator, Cell Culture Kits and the Aquatic Animal Experiment Unit, it was part of the First Material Processing Test P Life Sciences which flew aboard Spacelab-J in 1992. IML-2 experiments will add to experience gained during the earlier mission to evaluate how much microgravity increases the effectiveness of electrophoretic separation.

McDonnell Douglas Corp. flew a Continuous Flow Electrophoresis Experiment on several Space Shuttle flights in the early 1980s.

Operations: The Free Flow Electrophoresis Unit separates and analyzes the distribution of materials in a solution, using a method called continuous-flow electrophoresis. In this method, material to be separated is placed into a moving stream of buffer solution. As the material passes through an electric field, the components separate into individual streams within the solution. The constant flow of material allows processing of large quantities of product.

Three types of buffer solutions are contained in separate tanks. A crew member will inject the biological sample into the main electrophoresis unit, along with the selected buffer solution. The astronaut then will apply an electric field across the flowing solution stream to charge the particles suspended in it. Individual components within the mixture will separate into sub-streams, based on their relative charge and size, then flow into up to 60 separation collection tubes which can be stowed for post-flight analysis.

The crew in space and scientists on the ground monitor progress of the experiment through a display window at the top of the facility. Depending on the samples being studied, they can determine concentrations of the various separation products by how they scatter light or by how much ultraviolet light the products absorb.

Gravitational Role in Electrophoretic Separations of Pituitary Cells and Granules

Experiment Facility: FFEU
Principal Investigator:
Dr. Wes Hymer
Pennsylvania State University
University Park, Pa.

Objective: This experiment will use electrophoresis to separate pituitary cells which produce different hormones into single hormone producing components. The results will evaluate whether separation in microgravity is superior to separation on Earth. In addition, the experiment will help determine how pituitary growth hormone and prolactin, an immune-system controller, are affected by spaceflight.

Science: The pituitary system produces many hormones which regulate how the body functions. Two of the hormones which are produced throughout life are growth hormone and prolactin. Growth hormone not only promotes development of long bones during adolescence; it also increases muscle mass and promotes the breakdown of fat in adults. Prolactin plays a part in controlling the immune system and stimulating milk production in women after birth. Growth hormone and prolactin come from types of specialized pituitary cells which manufacture the hormones and store them in secretory granules inside the cells before release into the bloodstream.

Microgravity has been shown to negatively influence parts of this system in humans and animals. This experiment will attempt to determine whether the changes observed in pituitary cells after spaceflight are caused by an alteration to the surface of the cell, or by changes within the internal cell structure.

Significance: In addition to furthering scientific knowledge of electrophoresis techniques, this experiment will shed light on how spaceflight affects growth hormone and prolactin- containing cells and granules, information important to the long-term health of space travelers.

Background: Dr. Hymer studied rats from two Russian Biocosmos missions and from the 1985 Spacelab 3 mission. Post flight studies in each instance showed the rats' pituitary cells were less active after exposure to microgravity. Hymer's Shuttle middeck experiment aboard STS-46 in 1992 flew rat pituitary cells only, but the same changes occurred. This experiment takes his research to the next step, to help determine the reason for the changes.

Operations: Rat pituitary cells loaded in three cell culture chambers are the samples for this experiment.

Products of cells from one chamber will be stored in the Thermoelectric Incubator at 98.6 degrees Fahrenheit (37 !C) for most of the mission. Astronauts will periodically extract samples of the cell products with a syringe and refrigerate them for post flight analysis. Scientists will use these samples to determine structural and functional changes induced by various durations of exposure to microgravity.

A crew member will separate cells carried in the second chamber into 30 Free Flow Electrophoresis Unit tubes. These 30 samples will be cultured in space to determine how the cells function after separation.

On Flight Day 5, pituitary cells from the third chamber will be broken apart into sub-cellular particles. Electrophoresis will be used to separate prolactin and growth hormone granules. The granules will be frozen for post flight analysis to determine if internal changes occurred during the first five days of flight.

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

Experiment Facility: FFEU
Principal Investigator:
Dr. Hidesaburo Kobayashi
Josai University
Saitama, Japan

Objective: This experiment will employ a sensitive method for electrophoresis called isoelectric focusing to separate chromosome DNA from a nematode worm.

Electrophoresis is a process for separating biological materials into individual components using electric fields. This experiment uses isoelectric focusing, one of several methods for performing continuous flow electrophoresis. Isoelectric focusing is an advanced electrophoresis technique for producing very pure separations of proteins, viruses, cells and other biological materials on a small scale.

Science: Chromosome DNA, or deoxyribonucleic acid, is the element of a cell nucleus which is the molecular basis for heredity in many organisms. The small nematode is an excellent animal for studying the genetic basis for animal development. It is transparent, and its cellular structure is simple, with just six chromosomes.

Because chromosome DNA has nearly constant electric charge density, it cannot be separated from tiny organisms like the nematode worm using standard electrophoresis techniques. Therefore, this experiment will separate the nematode chromosomes based upon their molecular sizes and minimal charge differences. Since there is no gravity-induced convection or mixing in space, the electric charge should be dominant, resulting in a successful separation.

Normally, the solution in which samples are suspended for electrophoresis has a uniformly neutral pH (acid/alkaline) level. In isoloelectric focusing, the pH is graduated from more alkaline to more acidic levels across the buffer solution. The speed with which various molecules move during separation varies according to buffer solution pH levels. Different molecules stop moving, or reach their “isoelectric point,” at known pH levels. Therefore, scientists design isoelectric focusing experiments so motion of the material they want to collect halts at a given pH level, and unwanted materials pass on to different parts of the buffer solution.

Significance: The ability to separate chromosomes and test the method in space may help solve problems in genetic mapping and molecular biology.

Operations: An astronaut will inject concentrated suspensions of chromosome DNA into the Free Flow Electrophoresis Unit, along with a special buffer solution designed to test isoelectric focusing.

The solution will create a pH (acid/alkaline) gradient in the flow to allow separation of materials with small charge differences. After the suspensions are separated, the astronaut will stow the products in separation tubes for post flight analysis. Investigators on the ground will subject the chromosomes to standard genetic and biochemical tests.

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

Experiment Facility: FFEU
Principal Investigator:
Mr. Tsutomu Okusawa
Hitachi, Ltd.
Ibaraki, Japan

Objective: This experiment grows animal cells in cultures, then separates their cellular secretions in the Free Flow Electrophoresis Unit. Animal cells synthesize substances which can be valuable medical drugs. Investigators believe that two fundamental aspects of pharmaceutical production, the rate of separation and the amount of separated product, may be improved by space processing.

Electrophoresis is a process for separating biological materials into individual components using electric fields. It is expected that the method is useful in the production and purification of drugs and medicines on Earth.

Science: Drugs expected to work for cancer diagnosis and treatment include monoclonal antibodies, which are effective for both treatment and prevention because they provide a disease immunity. These antibodies are obtained from cultured animal cells on Earth. In the present commercial production method, animal cells are multiplied to the highest concentration possible in cell cultures. A recent method for culturing animal cells on the ground is being used to grow cells at ten times the previous rate. Then, the useful substance is separated from the culture medium through a refining process. After the medium is passed through a series of filters, final removal of unnecessary substances is accomplished by a process called liquid chromatography. However, the method is complicated and inefficient. The substances must be refined further to obtain a pure pharmaceutical product in larger quantities.

Ground-based electrophoresis has been used to analyze the separation process. It has not been practical for commercial processing, though, because convective flows within the separation fluid caused by gravity reduce its effectiveness.

Separation by electrophoresis in space shows promise for yielding larger amounts of a purer product. In addition, previous experiments indicate that the cells may produce antibodies at much faster rates in microgravity.

Significance: Results from experiments such as this should verify the validity of the electrophoresis method in space and provide useful knowledge for establishing space-based biotechnology production in the future.

Operations: A crew member will place one type of hybrid animal cell from the Cell Culture Kits into the Thermoelectric Incubator, both IML-2 life-science equipment furnished by the Japanese Space Agency. The culture will incubate and grow for five days. Then, the highly concentrated cell solution will be injected into the Free Flow Electrophoresis Unit, where the cellular secretions will be separated from the solution.

The sample will be separated under three different conditions, varying flow rates and the timing and intensity of electrical charges. The crew member operating the experiment and ground controllers will determine which conditions proved the most effective. The fractions of the sample separated under those conditions will be collected and frozen for post- flight analysis.

Aquatic Animal Experiment Unit (AAEU)

Payload Developer: NASDA

Objective: The facility provides an environment supporting studies of live fish and small amphibians under microgravity conditions. It permits observations of spawning, fertilization, embryonic stages, vestibular functioning and behavior in microgravity.

Hardware: This aquarium consists of two independent life- support systems, called fish and aquarium packages.

Small fish and amphibians, such as newts, live in four cassette-type aquariums, and there is a larger tank designed for fish. A special life-support system supplies oxygen, removes carbon dioxide and waste (such as ammonia and organic substances), and regulates the temperature as desired, between 59 and 77 degrees Fahrenheit (15 to 25 degrees C). The crew can view the animals through a window and access them by means of a port in each enclosure.

A video system can be attached to the viewing port for recording observations of behavior, such as swimming patterns. Close-up 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 supporting the mission on the ground.

Background: The AAEU was flown successfully on the Spacelab-J mission (STS-47), in a slightly different configuration. It was referred to as the vestibular function unit, and supported studies with carp.

Mechanism of Vestibular Adaptation of Fish under Microgravity

Experiment Facility: AAEU
Principal Investigator:
Dr. Akira Takabayashi
Fujita-Gakuen Health University
Toyoake, Japan

Objective: This experiment further explores the hypothesis that space motion sickness is caused by conflicting messages sent from the eyes and the otoliths. Investigators expect to clarify the interaction between otolith organs located in the inner-ear and other gravity-sensing organs. Six goldfish will be used to study how their vestibular systems adapt to microgravity and readapt to Earth's gravity after landing.

Significance: Space motion sickness usually is experienced by roughly half of all human space travelers, and may occur in other species. The investigator's team wants to evaluate mechanisms which may cause space motion sickness. This will help the effort to develop preventive measures.

Science: On the ground, animals control their posture and motion by sensing gravity by means of their vestibular and eye system. Posture control is achieved by integrating information in the brain received from both the eyes and vestibular system. When animals are placed in microgravity, they tend to lose their balance, then gradually adapt with time.

The most important gravity-sensing mechanism is the vestibular-otolith system in the inner ear on both sides of the goldfish. However, in microgravity, goldfish might maintain their balance only by visual input.

Background: This experiment is an extension of an experiment flown as part of Spacelab-J (STS-47).

Operations: In goldfish, the vestibular apparatus contains two otolith organs. Before launch one or both otoliths will be removed by surgery from five goldfish; a sixth goldfish will have both otoliths intact. All six goldfish will be flown in the Aquatic Animal Experiment Unit.

The fish behavior will be videotaped once a day and analyzed after the mission. One aspect of behavior to be observed is how the fish react to light stimulation from a direction perpendicular to the aquarium (dorsal light response). Swimming patterns, including measurements of the tilting angle, velocity, and how these characteristics change over time, will be studied to learn how the fish adapt in microgravity.

After Columbia lands, the readaptation process to Earth's gravity will be observed for 10 days.

Otoconia: Early Development of A Gravity-Receptor Organ in Microgravity

Experiment Facility: AAEU
Principal Investigator:
Dr. Michael L. Wiederhold
University of Texas Health Science Center
San Antonio, Texas

Objective: The purpose is to study how the gravity-sensing organs located in the middle ear develop in microgravity using embryos of the Japanese red-bellied newt. Scientists will study the development of both the gravity-sensing otolith organs and angular-acceleration sensors, the semicircular canals.

Science: All vertebrates (creatures with a spinal column) and most invertebrates have specialized receptors in their inner ears to sense gravity. In many organisms, including humans, this gravity perception occurs in organs known as otoliths. The organ contains mineral crystals called otoconia. The organ detects gravity by an interaction of the otoconia and tiny hairs (cilia) inside the inner ear. The crystals have greater density than the fluid surrounding them, so gravity pulls them down. The fall of the crystals (stones) on the hairs deflects hair bundles on top of the hair cells, causes excitation of vestibular-nerve fibers to the brain indicating body position.

There is uncertainty about how the crystals, their associated receptor cells and the connections of the nerve fibers within the brain develop in space without gravity.

The investigator's team wants to clarify this reflex process and also study growth development in the absence of gravity.

Significance: Observations should clarify gravity-dependent vestibular information processing. These findings will help explain the fundamental role of gravity on the otoliths and how it affects development of balance control.

Operations: The development process of the vestibular system including rotational acceleration sensors or semicircular canals will be investigated using Japanese red-bellied newts. Newts are very suitable for this experiment because these animals' vestibular system can develop within the planned IML-2 mission duration of 14 days.

Female newts will be used, since they store the fertilized eggs in their bodies. The crew injects some of the newts with a hormone during the spaceflight to observe the early development of the gravity sensor in an embryo grown in a microgravity environment. The size of the otoliths and associated sensory structures will be determined 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 four days apart. Otolith function will be assessed by examining the newts' larvae vestibular- ocular reflex.

Data from the newts flown in microgravity will be compared to controls on the ground, to embryos whose growth began three to five days before launch, and to newt embryos whose growth began on orbit. By comparing these groups, the investigators can determine if otoconial formation proceeds normally in microgravity.

Fertilization and Embryonic Development of Japanese Newts in Space

Experiment Facility: AAEU
Principal Investigator:
Dr. Masamichi Yamashita
Institute for Space and Astronautical Science
Kanagawa, Japan

Objective: Unique aquatic animals will be used to investigate the effects of gravity on cells during early developmental stages.

Science: Previous experiments have indicated that gravity affects amphibian eggs before their first cleavage. A single egg divides into many cells, and those cells mature or differentiate to form all the organs whose function makes up the living organism. Gravity is one factor that regulates this process. By studying cell differentiation in microgravity, scientists may be able to determine the effects of gravity on cells at early developmental stages.

The Japanese newt starts its life from a large, single-cell egg. Gravity plays a role in the egg's development by orienting the heavy vegetal hemisphere of the egg downward. Early stages of development may be very sensitive to gravity. This may occur even before the single cell divides into two cells. To investigate this effect, scientists will study newt eggs exposed to microgravity.

Significance: Fertilized newt eggs will be observed during the most dynamic stage of their life. Findings on the effects of the absence of gravity on their early development could help scientists acquire knowledge about the benefits of Earth's gravity for a biological system in early developmental stages and the mechanisms involved.

Background: The experiment on IML-2 may enrich scientific results and provide a larger number of specimens to establish a good statistical base. It also provides an opportunity to compare data from independent experiments. This "AstroNewt" experiment also is scheduled to fly on the first mission of the Space Flyer Unit. This Japanese space platform will be launched by an H-II rocket.

Operations: Japanese red-bellied newts mate in the autumn. The female newts go into hibernation, storing sperm in their bodies for fertilizing their eggs in the springtime. The hibernating newts will be collected and stored under controlled conditions until just before the STS-65 launch. Hibernation can be successfully terminated at any time by warming the creatures to 59 degrees Fahrenheit (15 degrees Celsius).

During the IML-2 mission, four newts will be kept in three water tanks in the Aquatic Animal Experiment Unit onboard Columbia. The female newts will be induced by a hormonal treatment to lay eggs in the water tanks. Two newts will receive a hormone injection on the ground prior to launch. This should result in their laying eggs three to four days later. Crew members will inject the other two newts in space.

When space-borne eggs are obtained, those eggs are isolated from the mothers by a partition. Close-up video images of the eggs and embryos will be recorded to trace their time course of development.

Some embryos will be preserved at specific development stages, while some will continue further development after Columbia lands. They will be kept until they hatch on Earth for the morphological and behavior studies.

A simultaneous control experiment will be conducted on the ground.

The adult newts and eggs will be shared with Dr. Wiederhold's "Otoconia" experiment.

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

Experiment Facility: AAEU
Principal Investigator:
Dr. Ken-ichi Ijiri
University of Tokyo
Tokyo, Japan

Objective: To study whether the freshwater fish, Medaka, can mate and lay eggs under the weightlessness conditions of spaceflight. If eggs are laid, scientists will study their development. The swimming behavior of this special strain of Medaka also will be observed during and after the flight.

Significance: Aquaculture in space could become an important nutritional theme in the future. Fish may be included in a controlled ecological life-support system being developed for long-term human stays in space.

In a practical system, fish would mate and spawn eggs, thus increasing their numbers. This experiment tests the feasibility of such an aquaculture design in microgravity, checking the mating behavior and embryonic development of a small fish. Results may help scientists plan other experiments for breeding fish in space.

Science: Medaka is a small freshwater fish commonly found in ponds and rivers all over Japan's countryside. It is an excellent experimental species because it has a relatively short life cycle of three months from one generation to the next. Also, the transparent body provides for easy observation and identification of its organs during embryonic development. Therefore, scientists can determine whether microgravity impacts normal development processes.

Fish usually swim in loop patterns when they are exposed to microgravity. However, a special breed of the Medaka species has not exhibited this behavior when exposed to microgravity for short periods of time on parabolic flights aboard aircraft. This tolerance to microgravity should be inherited by future generations of this breed. This experiment will examine whether this strain continues to swim normally during a longer stay in space.

Operations: Two pairs of male and female Medaka will be transferred to a small cassette-type aquarium about two days prior to launch. The life support for the Medaka is continuously provided by the Aquatic Animal Experiment Unit for the entire mission.

Each day, mating behavior should be completed within two hours after the transition from a 10-hour dark period to light period. After crew members visually verify the first spawning onboard Columbia, a video camera will record activity for the first two hours of the light period, which should be enough time to record the fish mating behavior.

Once spawning starts, the fish will continue to lay eggs once every day for a month. Newly laid eggs first form a cluster on the belly of the female fish. After a few hours, the eggs fall away from her body. The detached eggs should flow with the water into an area separated by a mesh structure. The crew will continue video observations of the developing embryos at predetermined intervals. Detailed observations

of its early embryonic development are possible because the egg envelope is transparent. The fry are expected to hatch about eight days after spawning. Investigators expect to see hatched fry swimming in the aquarium during the mission. They also are interested in the swimming behavior of the fry and adults after Columbia lands.

Genetic studies of the fish will be conducted post flight. Computer analysis of fish movement based on the video images recorded on the ground and in orbit is also planned.

Applied Research on Separation Methods Using Space Electrophoresis
Recherche Appliquee sur les Methodes de Separation en Electrophorese Spatiale
(RAMSES)

Payload Developer: The French Space Agency (CNES)

Objective: Scientists will conduct experiments using RAMSES to better understand the basic mechanisms that govern electrophoresis and assess gravity's impact on the process. Separating and collecting ultra-pure components of biological substances is an area of research with great importance to the pharmaceutical industry. Electrophoresis is a process for separating biological materials into individual components using an electrical field. These purified materials can then be used for other processes, such as growing crystals. This technology has been adapted for use in microgravity in the RAMSES electrophoresis unit. RAMSES is the French acronym for Applied Research on Separation Methods using Space Electrophoresis. This multi-user facility was developed by the French Space Agency in conjunction with European industrial partners.

Gravity-induced fluid movements such as sedimentation (settling of heavier elements in the solution) and convection (flows within fluids caused by temperature and concentration differences) tend to remix the compounds during separation on Earth. RAMSES will allow researchers to escape these limits by taking advantage of the reduction of gravity-induced phenomena in space.

The basis of the electrophoresis separation process is complex. Biological molecules in a fluid carry electric charges. Each type of molecule moves within an electric field at different speeds depending on its charge polarity, size and shape. For example, a molecule that is very negative will feel greater attractive and repulsive forces from the electric field than a slightly negative particle. Consequently, it will move more quickly than the molecule possessing less charge. The fluid in which the particles are suspended also plays a role in this process. The viscosity of the fluid or carrier solution hinders the forward movement of large molecules.

With the virtual absence of convection and sedimentation in microgravity, other important phenomena normally masked by gravity come into play, affecting the separation of molecules. Scientists are particularly interested in these electro-hydrodynamic effects. These are rotating movements of the liquid that are produced by the electric field.

Hardware and Operations: RAMSES is a continuous flow electrophoresis unit, meaning the biological sample to be purified is continuously injected into a carrier solution flowing up the length of a transparent separation chamber. An adjustable electric field is applied across the flow, causing the differently charged components to diverge into a wide beam consisting of separate streams. The separated streams of molecules pass through 40 outlets into collection tubes. A light absorption instrument, called a photometer, monitors the process. When it detects a significant concentration of biological material in the outlet flow, crew members will recover those collection tubes which, after storage in a refrigerator, will be returned for analysis. Otherwise the flow is diverted to a waste tank.

Separation parameters -- flow rates, electric field strengths and carrier fluid temperature -- can be altered to study a wide range of conditions. This will allow the optimum separation conditions to be determined. Crewmembers can monitor the separation experiments and photograph them through a transparent window

in the instrument front panel. A specialized light source provides a “sheet” of illumination across the separation chamber, producing a cross-sectional view of the sample flow behavior.

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 connections with the science team on the ground. Crew members can also make adjustments. The crew will be responsible for setting up operations, monitoring the separation process and the photometer which indicates the collection tubes that are gathering the highest quality samples. These are the samples that will be returned to scientists on the ground for further research.

Optimization of Protein Separation

Experiment Facility: RAMSES
Principal Investigator:
Dr. Victor Sanchez
National Center for Scientific Research (CNRS) Chemical Engineering Laboratory
University Paul Sabatier, Toulouse, France

Objective: This investigation will use a unique process to separate protein solutions into individual components using an electric field. The process is called electrophoresis. Solutions of proteins will be purified by separating them into several streams, each one containing proteins of only one kind. Just one milligram (a thirty thousandth of an ounce) of protein purified for use in pharmaceuticals can be very expensive. Performing this purification in the absence of gravity may allow scientists to gather purer protein in larger quantities than is possible on Earth.

Two series of experiments will be conducted to evaluate the degree of protein purification that is possible in microgravity. Three samples each contain two pure proteins that have been mixed together. This will allow the process to be tested with well-known products. Three other samples contain a great number of proteins extracted from a bacterial culture. Here most of the proteins are unidentified, and scientists are interested in how these solutions will separate. Another objective is to test whether the biological activity remains intact in the purified product.

Science: A protein molecule is a complex structure that has an electric charge. Each type of protein moves at a different rate across the chamber when exposed to an electric field. Therefore, when a solution of protein molecules is passed through a separation chamber, the molecules will move away from the side with the same charge toward the opposite-charged side of the field. The particles will separate and fan out into an array of bands as they flow through the chamber. At the outlet they can be collected for further research.

The principal investigator’s team hopes to study a three-fold combination of effects:

- how the separation process is affected by the strength of the electric field and by the length of time spent traveling through it
- how the protein molecules interact with ions and molecules of the carrier solution
- electro-hydrodynamics, a rotating movement of the carrier liquid caused by disturbances in the electric field due to the presence of the protein.

Significance: Tomorrow’s pharmaceuticals will be developed using proteins produced by biotechnology. Therefore, scientists require a precise knowledge of protein structure. To obtain this, highly purified protein molecules are necessary in sufficient quantity to allow protein crystals to be formed.

Working in microgravity eliminates buoyancy forces, allowing scientists to use more highly concentrated protein solutions, higher electric field strengths and slower carrier flow rates for longer separation times.

Background: IML-2 scientists will build on past progress with continuous flow electrophoresis operations in microgravity by studying a variety of biological materials and further characterizing this type of processing and the operating conditions that affect it. Investigations into electrophoresis for separating biological materials began in the 1950s. McDonnell Douglas Corp. conducted several experiments onboard the Space Shuttle during the 1980s. This French team of investigators became interested in this process in the mid- 1980s.

Operations: In continuous-flow electrophoresis, a stream of carrier solution flows through a thin, rectangular chamber. When a protein mixture is injected into this flowing solution, it moves with the flow and an electric field causes the proteins to move apart across the width of the chamber. A direct current field is used here to keep the proteins always moving in the same direction. A photometer (measuring light absorption) will be used during operation for measuring protein concentrations in the 40 samples. A crew member will refrigerate the samples with the highest protein concentrations, which will be returned for post flight analysis. The first sample to be treated will contain two colored proteins. These are easily separated and will be processed under the same conditions as on Earth. This will demonstrate that the instrument is operating correctly on its maiden flight. This instrument can treat up to one milligram of protein per hour, which is considered a large amount of matter.

Electrohydrodynamic Sample Distortion

Experiment Facility: RAMSES
Principal Investigator:
Dr. Robert Snyder
NASA Marshall Space Flight Center
Huntsville, Ala.

Objective: This experiment focuses specifically on electro- hydrodynamics. This is the movement of liquid driven by an electric field. In this case, the movement will be made apparent by the use of a suspension of latex particles in liquid. Scientists will examine how the shape of a stream of particles is modified by an electric field.

Electro-hydrodynamic effects are more easily observed in the absence of gravity, where convection caused by buoyancy is virtually eliminated. Sedimentation, the settling and separation of heavier elements from lighter ones, also is greatly reduced. The principal investigator's team plans to stop the flow of a carrier liquid and immobilize the stream of latex particles. On Earth, the particles would immediately settle to the bottom of the chamber. In microgravity, the originally cylindrical stream of particles should be deformed by the electric force without interference from any other movement.

Significance: Continuous-flow electrophoresis is a process that allows protein mixtures, or living cell populations, to be separated into batches of highly purified products in sufficient quantity for them to be used in other processes, such as protein crystallization.

However, before highly concentrated samples can be processed on a large scale, the factors governing electrophoresis must be more fully understood. One is the electro-hydrodynamic spreading of a sample stream in electrophoresis, resulting in remixing of the components that are meant to be separated, thus harming the purity of the product.
Improved understanding of the physics underlying electro-hydrodynamics will help scientists better control this phenomenon and thereby improve the separation in electrophoresis. Microgravity allows highly concentrated samples to be used and observations to be made even when the carrier flow is entirely stopped.

Science: Latex particles are bigger and less complex in structure than protein molecules so they are easier to study. Like proteins, the latex particles retain a positive or negative charge. This means that they also can be influenced by an electric field.

The electric field around a stream of latex particles can be distorted either by varying differences in electrical conductivity or by using differences in dielectric constant. The manipulation of electrical conductivity in theliquid results in local areas through which electric current passes more easily, and areas of greater opposition to current flow. The result is a non-uniform field in the liquid.

The dielectric constant involves the way in which molecules or particles tend to be oriented by an electric field. A non-uniform field causes the liquid in and around the latex-particle stream to rotate, showing up as a change in shape of the stream of particles.

Background: Electro-hydrodynamic effects such as these were originally observed in the 1960s. Previous continuous-flow electrophoresis experiments exhibited electro-hydrodynamic spreading of the sample stream when electrical properties (such as conductivity and dielectric constant) of the sample stream were not the same as those of the carrier solution.

Operations: Two different samples will be used to study the effect of varying the latex-particle concentration. The suspension of latex particles will be injected into a carrier solution flowing through the separation chamber of the RAMSES electrophoresis unit.

The first part of this experiment uses AC fields, in which the positive and negative poles of the field are rapidly switching. The latex particles should not exhibit any net movement, allowing the electro-hydrodynamic effect itself to be observed. As the solution flows through the chamber it should widen into a continuous ribbon of latex particles. A thin sheet of light will illuminate a cross-section of this ribbon so that a crew member may view and photograph any distortions to the flow of latex particles.

Advanced Protein Crystallization Facility

Payload Developer: European Space Agency (ESA)

Objective: Advanced Protein Crystallization Facility (APCF) research has two objectives: to provide difficult-to-produce, biologically important protein crystals for analysis, and to determine the physical mechanisms that govern protein crystal growth. It is the first space facility ever designed to use three different protein crystal growth techniques.

Significance: 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 medicines. For example, the pharmaceutical industry uses structural information to design drugs which bind to a specific protein, blocking chemically active sites. Such a drug fits a protein like a key in a lock to “turn off” the protein’s activity, thus regulating metabolic processes.

The three-dimensional structures of proteins are determined by X-ray analysis of protein crystals. However, many proteins that interest medical researchers have not produced crystals of adequate size and quality to allow X-ray data to be collected. Crystals grown in space, where they are virtually free from the distortions of gravity, often provide better structural information than their counterparts grown on Earth.

Hardware: The Advanced Protein Crystallization Facility is a fully autonomous facility except that it requires electrical power from the Shuttle and activation by a crew member when orbit is reached. Temperature control, any value between 4 and 25 degrees C is possible, activation/deactivation of the protein growth chambers, monitoring of basic housekeeping parameters, video image taking and recording of all data on a digital tape recorder are performed under control of a microprocessor. Two experiment units exist, each of which occupies one Shuttle mid-deck locker. For IML-2, both units will be held at a constant temperature of 68 degrees Fahrenheit (20!C). Each unit can accommodate 48 modular protein crystal growth chambers, 12 of which can be observed with a high- resolution, black and white video camera. Chambers for each of the three crystallization techniques are available in different volumes. All

types and volumes of chambers are interchangeable within the units, so researchers can choose the best combination for their particular studies.

The three protein crystallization techniques available to users of the facility are:

Vapor diffusion: The protein 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 precipitant solution are initially separated by shutters. When the shutters are removed, the precipitant 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 thin membrane of material that allows passage of some substances while blocking others. The precipitant moves across the membrane into the protein solution, initiating crystal development.

Operations: The crew activates the Protein Crystallization Facility after reaching orbit, monitors the facility as it operates, and deactivates the equipment when experiments end. No data are transmitted to the ground during the mission.

Crystal growth begins by causing a protein solution to “supersaturate,” a condition where more protein is present than can remain dissolved within a volume of fluid. As a result of this supersaturation, the protein crystals precipitate out of solution and begin to grow.

Video images will be made of crystals as they form. After the mission, the approximately 5,000 images will allow investigators to study the history of crystal development in microgravity.

Background: This experiment facility was developed by the European Space Agency. It has flown once before, on the Spacehab-1 mission (STS-57) in 1993.

Principal Investigator	Proposed Protein(s)	Method
N. Chayen/P. Zagalsky Great Britain	alpha Crystacyanine	vapor diffusion
A. Ducruix/M. Ries	Collagenase diffusion	vapor
CNRS Laboratory of Crystallography Gif sur Yvette, France	Rhodobacter Spheroides	liquid-liquid diffusion
V. Erdmann/S. Lorenz Free University of Berlin Berlin, Germany	RNA	vapor diffusion dialysis
R. Giege/A. Theobald CNRS Institute of Molecular and Cellular Biology Strasbourg, France	Aspartyl-tRNA Synthetase	vapor diffusion dialysis
W. deGrip/J.V. Oostrum University of Njimegen Nijmegen, The Netherlands	Rhodopsin	vapor diffusion
J. Helliwell/E. Snell University of Manchester Manchester, England	Lysosyme (collaboration with Sjolin)	dialysis
J. Martial/L. Wyns Belgium	Octarellin Copperoxalate liquid-liquid diffusion, dialysis	vapor diffusion
A. McPherson/S. Koszelak U. of California at Riverside Riverside, California	Satellite Tomacco Mosaic Virus Satellite Panicum Mosaic Virus Cucumber Mosaic Virus Turnip Yellow Mosaic Virus	liquid-liquid diffusion
L. Sjolin Chalmers U. of Technology Goetborg, Sweden	Ribonuclease S (collaboration with Helliwell)	vapor diffusion
G. Wagner Justus-Liebig U. of Giessen Giessen, Germany	Bacteriorhodopsin	dialysis

Principal Investigator	Proposed Protein(s)	Method
A. Yonath/H. Hansen Max Planck-Laboratory for Ribosomal Structure Hamburg, Germany	Haloarcula marismortui 50S	vapor diffusion
F. Jurnak U. of California at Riverside Riverside, California	Pectate lyase liquid	liquid diffusion
M. Garavito University of Chicago Chicago, Illinois	OmpF porin	liquid-liquid diffusion
K. Ward Naval Research Laboratory	Aequorin Phosphoilpase A1 Green fluorescent protein	liquid-liquid diffusion
H. Einspahr Bristol-Meyers-Squibb	Cytochrome c (tuna)	liquid-liquid diffusion
P. Weber DuPont	Alpha-thrombin (human)	liquid-liquid diffusion

Bubble, Drop and Particle Unit

Payload Developer: European Space Agency

Objective: Subtle aspects of fluid physics, normally hidden by the effects of Earth's gravity, will be investigated in microgravity with the Bubble, Drop and Particle Unit, developed by the European Space Agency.

Researchers will study fluid behaviors and interactions such as bubble growth, evaporation, condensation, thermocapillary flows (fluid motions generated by temperature differences along the surfaces of liquids). Such phenomena are difficult to observe on Earth because their effects are masked by gravity-induced fluid movements.

Science: 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, drops of liquid become spherical, instead of teardrop, as their shape becomes dominated by surface tension effects instead of gravity.

Significance: Results 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. 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.

Hardware: Crew members will exchange interchangeable experiment test containers with dedicated fluid cells located in the Bubble Drop and Particle Unit. The fluid 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.

Modular optics components support several different diagnostic techniques, including Schlieren (shadowgraph), interferometric and infrared imaging. The sample can be illuminated using fluorescent lamps, or a Helium-Neon laser. Experiments are automatically controlled by a microprocessor. Investigators on the ground can monitor the processing of their experiments and can change parameters. Crew members can also adjust and modify conditions.

Cameras and sensors will observe and record temperature, density, position and interactions within the liquid-filled test cells.

Bubble Migration, Coalescence and Interaction with Melting and Solidification Fronts

Experiment Facility: Bubble Drop Particle Unit (BDPU)
Principal Investigator:
Dr. Rodolfo Monti
University of Naples
Naples, Italy

Objective: Bubbles form as molten alloys, crystals and glasses begin to solidify both on Earth and in microgravity. Scientists are interested in why these bubbles are not uniformly distributed within the metal, whether processed on Earth or in space. This investigation will use a transparent material to observe the movement of bubbles at the liquid- solid interface as the material first melts, then solidifies. It also will study how drops of liquid behave when exposed to a temperature gradient and interact with the solidification front -- the moving boundary where a molten substance is crystallizing into solid.

Significance: This research is significant for improving techniques for material processing in space. It is important to learn how to control the movement of bubbles in a material during phase changes, such as from liquid to solid. Scientists are interested in knowing how to solidify materials, both with the bubbles included and excluded from the substance.

These findings have potential applicability for industries in areas such as the production of crystals in electronic devices. Another area of industrial interest is refining the capability to disperse one material into another with extremely high uniformity by controlling the Marangoni migration of inclusions in melts. This is the movement of bubbles or drops driven by surface forces when a liquid's surface tension is affected by heat, in the form of a temperature gradient.

Science: On Earth, gravity-induced convection and buoyancy alter processes that would benefit from gravity- and disturbance-free conditions. This experiment will allow scientists to observe bubble movement and the interaction with the solidification front in the absence of gravity with bubble-drop dimensions not achievable on the ground.

Operations: The test sample will be a solid piece of tetracosane, a transparent material that melts at a low temperature. The material sample includes pre-formed bubbles of different sizes.

The tetracosane will be heated above its melting point 131 degrees Fahrenheit (55 degrees Celsius). As the melting front reaches each bubble, the bubble will be released and is expected to migrate toward the hot side of the liquid, away from the melting front. The locations, dimensions and movement of the bubbles released by the melting front will be recorded. Other characteristics of the migration will be studied and documented.

Thermocapillary Migration and Interactions of Bubbles and Drops

Experiment Facility: Bubble Drop Particle Unit (BDPU)
Principal Investigator:
Dr. R. Shankar Subramanian
Clarkson University
Potsdam, NY

Objective: This experiment will study the movement and shape of gas bubbles and liquid drops in silicone oil when a temperature gradient is established within the container. The bubbles are expected to move from a position near the cold wall toward the hot wall. The gas bubbles and liquid drops will have a range of diameters and densities.

Significance: 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.

Science: Bubbles do not behave in space like they do on Earth. By managing bubbles and drops and measuring how fast they move because of a temperature difference, scientists may be able to predict various engineering applications and hardware designs. This heating and cooling simulates the melting and solidification of metals and other basic scientific principles used in other experiments.

The investigator's team will study how fast the bubbles move, their size and shape. These data will be compared with mathematical predictions.

Operations: A series of experiments, each lasting about four hours, will be conducted. Before each series, a temperature gradient will be established in the container. Thereafter bubbles and drops will be injected into a small rectangular cell filled with a fluid. Approximately six bubbles (or drops) will be injected in sequence. Their motion will be monitored on the ground via video. Then, the bubbles or drops will be extracted through an extraction net, in preparation for the next series of runs. Results from the experiments will be compared with predictions from theoretical models. Temperature control and bubble/drop injection can be performed automatically and under control of the investigator on the ground or by an IML-2 crew member.

Bubble Behavior Under Low Gravity

Experiment Facility: Bubble Drop Particle Unit (BDPU)
Principal Investigator:

Dr. Antonio Viviani
Seconda Universita degli Studi di Napoli (SUN)
Aversa, Italy

Objective: This experiment investigates how different size bubbles of inert gas move within a liquid. The liquid, n- heptanol, will be subjected to an uneven temperature distribution. The membrane encasing the gas bubble will react to the temperature variation within the liquid. The membrane toward the colder temperatures contracts -- a result dependent on a surface tension change on that portion of the membrane -- causing the bubble to move.

The motion of the bubbles is driven by variations in the surface tension, which are induced by temperature differences along the interface (thermocapillary effect), between the liquid and the bubble. This particular kind of liquid permits measurement of an unusual, non-linear temperature- dependent surface tension. The fluid region where surface tension is at a minimum is of great interest.

Science: This phenomenon can be illustrated with an analogy. Soiled clothes are washed in hot water which relaxes the surface tension of the cloth fibers permitting the dirt to be extracted. This investigation will use temperature differences and thermodynamic principles to move and extract bubbles. Scientists also want to determine if higher temperatures will cause bubbles in molten glass to migrate to an exterior surface so they can be eliminated.

Significance: Earth's gravitational field acts on density differences between air and liquid, making buoyancy forces predominant. In the absence of gravity, density is eliminated and only the effects of surface tension are observed. The effects of this phenomenon on Earth are masked by buoyancy. In space, scientists can observe how bubble movement is affected solely by surface tension to gain a better understanding of the role surface tension plays on Earth.

Operations: Bubbles of inert gas will be injected into the liquid n-heptanol under a temperature gradient. Investigators will determine the non-uniform velocity of the injected bubbles for different temperature ranges. They want to observe the behavior of the bubbles when they reach the center of the container where the surface tension will be at a minimum and the bubbles are expected to stop.

The experiment will be repeated with several bubbles of varying size. The temperatures of the chamber walls will be varied. Sometimes the bubbles will move toward the hotter chamber wall. At other times, they will move toward the cold wall.

The investigators also plan to inject two bubbles to observe what happens when they come together. Images of the bubble migration will be recorded and sent to investigators on the ground. The experiment sequence is three-fold: establish optimal temperature conditions, inject bubbles, and extract the bubbles using a net mechanism.

Interfacial Phenomena in a Multilayered Fluid System

Experiment Facility: Bubble Drop Particle Unit (BDPU)
Principal Investigator:
Dr. Jean N. Koster
University of Colorado
Boulder, Colo.

Objective: Even in everyday life, we frequently observe that some fluids, such as oil and water, do not mix. Instead, they form layers when placed in the same container. This investigation is designed to study what is happening at the place where the immiscible liquid molecules touch each other, called the liquid-liquid interface, when temperature-driven fluid motion is generated at the contact surface. The experiment will be conducted using a multilayered immiscible fluid system.

Science: Studying interface forces in low gravity will provide new and fundamental insight into a complex field of fluid physics that cannot be studied on the ground. Earth's gravity causes liquids to move convectively upward and downward when a temperature difference is generated across the surface of a liquid. So, in order to isolate and study fluid motion caused by temperature variations along the surfaces of fluids (thermocapillary motion), it is necessary to escape gravity's effects.

The interface tension-driven flow where the molecules of the different liquids interact is a complex process. An industrial interest in this process developed when investigators became interested in liquid-encapsulated crystal growth, where one liquid is processed while enveloped in another liquid. For example, gallium arsenide, a useful semiconductor material, has been grown using a liquid encapsulation technique to keep the arsenide, a toxic substance, from escaping.

Significance: This experiment will help scientists to better understand thermocapillary fluid physics. Physicists wanted a crystal growth furnace where the heating would not create convective flows, especially time-dependent flows, in the molten metal. Scientists believe this type of furnace, with liquid encapsulated electronic melt, could improve crystal growth in microgravity by reducing or eliminating the thermocapillary motion in electronic material.

Findings from this experiment will benefit research in other areas, including environmental science, geology, advanced aerospace materials development and future space power systems.

- Environmental scientists are interested in learning about the interaction between oil and the water it is floating on. Understanding immiscible fluid flows is of value for cleaning up environmental water pollution caused by oil spills.

- An interesting geological application will use this knowledge to study the Earth's mantle. Two convecting, adjacent layers have an interface that physically behaves in the same manner. Computer models are used to examine tectonic movement.

Operations: A special test container was developed for this experiment and that of Dr. Legros. Three fluids which do not mix are used to establish two liquid-liquid interfaces in this three-layer system composed of fluorinert, silicone oil and fluorinert. Until the experiment is begun on orbit, the three fluid layers are separated by two metal curtains in the container. At the initiation of the experiment these curtains will be retracted. Using temperature variations, fluid motions are initiated at the two liquid-liquid interfaces, such that motion at one interface competes with the other. Temperature-driven flow throughout all three fluid layers will be visualized using tracers inside the liquid.

Scientists on the ground will observe the behavior of the interfaces. For example, they will be able to study the interdependent interactions between the individual layers due to temperature gradients. These data will be compared with computer model results and will subsequently help validate the mathematical models. Findings will provide a better understanding of the underlying physics involved in these processes.

Thermocapillary Instability in a Three-Layer System

Experiment Facility: Bubble Drop Particle Unit (BDPU)
Principal Investigator:
Dr. Jean-Claude Legros
Free University of Brussels
Brussels, Belgium

Objective: Surface-tension forces within three layers of fluids will be studied. The investigator's team wants to learn how to control fluid flows within the middle layer.

Significance: Understanding these complex types of fluid flows and finding ways to control them are significant to the field of material science, particularly the specialized field of directional solidification. Directional solidification is a method for growing crystalline materials such as metals and semiconductors. In this technique, molten material is cooled so that the boundary between solid and liquid material moves from one end towards the other during solidification. It is this boundary region that is particularly significant to researchers.

Science: This experiment, along with Dr. Koster's investigation, is expected to provide the first information on the departure from the rest state of a multi-layer system under the influence of surface-tension forces. Using these findings, scientists should be able to devise ways to counteract or eliminate some of the undesirable effects of surface-tension forces in space.

The basic mechanisms which cause these types of flows are understood, but not the means for effectively controlling them. This type of control becomes highly desirable when, for instance, researchers want to create flawless silicons and metals for the electronics industry.

Operations: Experiment procedures will allow scientists to describe quantitatively the convective pattern arising in three layers of immiscible liquids, fluorinert, silicone oil, and fluorinert. The experiment will be conducted in a test container identical to that used in Dr. Koster's experiment. Curtains inside the cell, separating the three layers, will be retracted and heat will be applied. 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.

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

Experiment Facility: Bubble Drop Particle Unit (BDPU)
Principal Investigator:
Dr. Johannes Straub
Technical University of Munich
Munich, Germany

Objective: This experiment is designed to provide a better understanding of boiling processes. It uses vapor bubbles within a liquid to study the process of evaporation and condensation at a liquid interface, the point where a liquid phase of a fluid forms a common surface with its vapor phase.

Science: Evaporation occurs when a liquid changes to a gas due to increased heat. Condensation is the reverse process, when the gas cools to a liquid. Scientists will create a small gas bubble in an evenly heated, liquid refrigerant. The bubble will become larger as it draws heat from the liquid, until the temperatures of the liquid and gas reach a state of equilibrium.

Scientists will study physical changes during evaporation and condensation at the interface where the bubble contacts the liquid. In Earth's gravity, bubbles disappear very rapidly from the field of view, hindering such studies. In microgravity, the vapor bubble will remain where it is formed and grow in size, making it easier to observe.

Significance: Evaporation and condensation at liquid-gas interfaces are fundamental processes in our lakes, seas and rivers. The processes also have technical applications in heat exchangers, energy conservation systems and the chemical industry. A precise knowledge of the kinetics, or energy processes, which govern boiling, is important to understanding environmental effects and improving technical systems.

Background: The science team has conducted this experiment in the brief weightless conditions available during parabolic flights with a specialized Caravelle aircraft, a drop tower and a sounding rocket flight. However, this will be its first time in orbit.

Operations: A crew member will place a sealed aluminum container filled with Freon into the Bubble, Drop and Particle Unit. Heaters within the container will warm the refrigerant evenly from all sides. A compressor will increase pressure in the container to remove any air bubbles which may exist in the liquid, then reduce pressure so the liquid will reach a supersaturated state, where it remains liquid at a temperature above that at which it would normally become a gas.

Then, experiment scientists on the ground will command a short heat pulse from a spot heater, which will create a gas bubble inside the liquid. The bubble will draw heat from the supersaturated liquid and continue to expand until the gas and liquid reach equilibrium. Cameras and sensors will observe and record temperature, Freon density, and positions of the bubble. After each phase of the experiment, controllers will increase the pressure to condense the bubble.

They will repeat the experiment at six different heat levels, between room temperature and approximately 185 degrees Fahrenheit (85C).

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

Experiment Facility: Bubble, Drop and Particle Unit
Principal Investigator:
Dr. Dieter Langbein
ZARM Institute
Bremen, Germany

Objective: This experiment will record the behavior in microgravity of liquid surfaces, making precise measurements of the angles where liquids and solid surfaces meet.

Science: In a weightless environment, liquid movements due to gravity are minimized, allowing for observations of more subtle fluid dynamics, such as thermocapillary flows. This type of liquid movement becomes the main mechanism of heat transfer within fluids. During IML-2, this fluid investigation will confirm the existence and stability limits of liquid surfaces in a cylinder.

Significance: This experiment will give scientists insight into the wetting phenomena caused by capillary forces. The data collected during this experiment will also help design better surface-tension tanks (tanks that provide fuel at the outlet valve via capillary effects alone, without relying on gravity or pistons).

Equipment and Operation: Silica Matched Liquid Cargille 50350, a liquid which has the same refractive index as quartz, will be injected into the quartz test cell of the Bubble, Drop and Particle Unit. This test cell, which contains four different transparent, polygonal cavities with different wall angles, will be maintained between 68 and 175 degrees Fahrenheit (20 and 80 degrees Celsius), using heaters situated between each cell. The surface shapes produced as the temperature and liquid volumes are changed will be observed using background and cross-section illumination.

Background: IML-2 is the first on-orbit flight for this experiment. Previously, this investigation was conducted from sounding rockets launched in Sweden and inside a drop tower in Germany.

Critical Point Facility

Developed by: European Space Agency (ESA)
European Space Research and Technology Center
(ESTEC) Noordwijk, The Netherlands

Objective: Several experiments will be able to measure and visually record special fluid properties at their "critical point" with the Critical Point Facility, developed by the European Space Agency.

At the critical point, a fluid is neither a gas nor a liquid, it is both; more precisely, the material fluctuates back and forth in small volumes from one state to another so that the state of the total volume is indistinguishable. Scientists have been unable to study this interesting behavior closely in normal gravity.

In Earth's gravity, critical point experiments are difficult to perform due to the fluid being very compressible. Most of the sample cannot be maintained at the critical density because the fluid's own weight compresses part of the sample to a density greater than the critical density. The most critical region literally collapses under the weight of the fluid.

Significance: 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 magnetization changes in solids.

Information gathered from these experiments refines the physical theories that describe the mechanism and the rate of change of fluid states.

Background: On Earth, gravity blocks experimental efforts in working with pure fluid critical-point systems. The feverish experimental activity of the 1960s and 1970s in critical phenomena slowed in the 1980s partly because of gravitational limitations on the acquisition of experimental data closer to the critical temperature. However, some unexpected observations of near-critical fluids in low gravity have encouraged the study of equilibration dynamics with new enthusiasm in critical phenomena research.

Hardware Description: The facility is a multi-user system capable of accommodating the experiments of several researchers sequentially in any one mission. Interchangeable thermostats for controlling the temperature of an experimental sample are inserted in the facility, where they are surrounded by an optical diagnostics system to monitor the phenomena of interest.

Temperature is extremely important in critical point experiments. So, the facility was designed to provide extremely accurate thermal control of the test fluid.

The CPF hardware is composed of two interconnected drawers: the electronics and the experiment drawers.

The front panel of the electronics drawer allows the crew to manipulate the experiment via an alphanumeric key pad display, switches and lamps.

The experiment drawer contains a front panel access door through which different experiment thermostats can be inserted for processing.

A black and white video camera is a useful tool in the apparatus. This camera is used to monitor fluid dynamics of the sample when it undergoes temperature cycling during an experiment. A 35 mm camera is attached to the front of the experiment drawer for still photos. A laser and a light emitting diode, which serve as light sources for the experiment also are located inside the drawer.

The facility 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 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. These data show the local fluid density changes in various parts of the cell.

Operations: The sample fluid held near its critical density is housed within sealed cells. The cells are installed in a high precision thermostat which holds them at a temperature between 86 and 140 degrees Fahrenheit (30 and 60 degrees Celsius). 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. On Earth, this change takes place within a matter of seconds. In microgravity, the change happens uniformly over minutes, permitting scientists to gather large amounts of data.

Unusual density fluctuations occur at the critical point. These fluctuations strongly scatter the light and reduce its intensity. Detectors measure these variations. After the critical point has been crossed, these fluctuations diminish, and the sample forms patches of either liquid or gas phases.

Intermittent television video is available to investigators on the ground. Operators also gather nearly full-time digitized video snapshots at six-second intervals of the phenomena in progress. Once activated on orbit, the facility can operate in a fully automatic mode. Experiments are then conducted according to a prerecorded timeline. During the mission, however, the investigator’s team can send remote commands to modify their experiments in real-time after analyzing optical, thermal and pressure data received at Spacelab Mission Operations in Huntsville, Ala. More than 1,100 such commands were sent successfully during the first flight of the CPF on IML-1, during some 120 hours of continuous operation.

The Piston Effect

Experiment Facility: Critical Point Facility (CPF)
Principal Investigator:
Dr. Daniel Beysens
CEA Department of Condensed Matter Physics
Gif sur Yvette, France

Objective: This investigation explores a specialized field within fluid physics. A hot layer within a contained volume of fluid is generated and expands and heats the rest of the fluid in a way somewhat similar to compressing it with a piston. This unique phenomenon by which a particular temperature can become uniformly distributed throughout a container of fluid has been given the name, the "piston effect". The effect arises only in fluids when they are at or near their critical point, and therefore highly compressible, or elastic. Such highly compressible fluids can be easily compressed into a given amount of space. One result is that they are very sensitive to thermodynamic effects.

As part of this experiment, the principal investigator's team is interested in what will happen to the pressure within the sample cell during two Space Shuttle maneuvers which submit the test cell and fluid to a weak and controlled acceleration.

Science: When a substance is brought to its critical point condition and then heated beyond it, it has unique characteristics for a fluid and is said to be "supercritical." In this condition, one attribute of the substance is unusually high compressibility, or elasticity. A related property is that the fluid can exhibit very rapid transmission of heat through a type of flow similar to convection, but not caused by gravity. In fact, this type of transmission appears somewhat similar to the way sound waves travel through a fluid.

For a small fluid container, this piston effect form of heat transport occurs at a typical time range of between a hundredth of a second and 30-50 seconds, depending on the temperature relative to the fluid's critical temperature. This can be compared to "acoustic time," based on the velocity of sound -- which is in the range of only a few microseconds -- and "diffusion time," which is on the order of hours or even days for a substance near its critical temperature. The typical time for the piston effect is much longer than acoustic time, but shorter than diffusion time. It is a significant property because this is the time at which thermalization occurs. Thermalization, the process of a local temperature chance becoming uniformly distributed, for a supercritical fluid occurs at the typical time for this piston effect.

Significance: This research has potential to help us understand the effective management of fluids used in fuel cells and rocket propulsion tanks.

Another expanding field of study uses supercritical fluids in industrial extraction processes, because the supercritical fluids are remarkable solvents.

Background: Recent numerical simulations and experiments on sounding rockets, the first Spacelab International Microgravity Laboratory 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.

Operations: A number of experiments will be performed to determine the temperature, density, and pressure evolution using a temperature sensor or a laser beam as a local heat source. 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

Experiment Facility: Critical Point Facility (CPF)
Principal Investigator:
Dr. Richard A. Ferrell
University of Maryland
College Park, Md.

Objective: This experiment is designed to study the critical-point properties of a fluid composed of identical molecules. At the critical temperature, there is no distinction between the liquid and the gas. The two phases become indistinguishable.

During these phase changes, energy is received and released by either heat diffusion or subjecting the substance to pressure changes -- a form of work. Heat diffusion occurs very slowly near the critical point, while pressure changes (the mechanism of imposed work) happen rapidly within the fluid. Studying how these two energy-transfer mechanisms interact is the goal of this experiment.

Significance: While it is of fundamental scientific importance, this experiment will also provide results of importance to other low-gravity, critical-point experiments now under development. In order for researchers to plan the timelines for these experiments, it is necessary to determine how quickly their test samples will reach thermal equilibrium after temperature step changes near the critical point.

Science: Any pure fluid possesses a liquid-vapor critical point where liquid and vapor are no longer distinguishable. The fluid also is highly compressible. This compressibility is the root of difficulties posed by gravity, when attempting to study critical point phenomena. At a given temperature, the critical zone is too small on Earth to measure. But the absence of gravity reduces the weight of the fluid on itself and widens the critical zone for a given temperature, allowing scientists to maintain critical point conditions over a large enough region to allow studying the critical behavior in detail.

Background: The first thermal equilibration experiment flew on the first International Microgravity Laboratory mission in 1992.

Operations: The investigation has two experiments, each made up of two parts. One experiment is called “thermal equilibration-B.” It studies thermal transmission by the diffusion process, by setting up a steady heat flow across the cell, using a small heater attached to one side. Interferometry and light scattering will again be used to track the time evolution of density and temperature.

The second, “adiabatic fast equilibration,” studies how “pressure work” transports energy from one part of the test cell to another. Temperature changes will be induced both externally, by changing the temperature of the confining windows, and internally, by heat from a pulse of current passing through a resistance wire inside the cell.

When the wire is charged to a static potential of up to 500 volts, the sulfur-hexafluoride in the cell is pulled into the electric field around the wire, causing a local density change observable by an optical technique known as interferometry. The electric field allows for fast change of cell conditions without heat input. This is a unique way to study diffusion in non-critical fluids.

This investigation will be conducted with the fluid sulfur-hexafluoride. The thermostat for each experiment will hold two fluid cells with a layer of fluid about a sixteenth of an inch thick (1 or 2 mm) confined between transparent windows at the proper critical density. One cell will be for interferometry measurements and the other for visualization.

The response of the fluid in both thermostats will be monitored visually with a video camera as well as by interferometry and light scattering. Interferometry gives information on the local fluid density changes in

various parts of the cells. Light scattering becomes more intense near the critical point. Therefore, it is a sensitive measure of temperature changes.

Density Equilibration Time Scale

Experiment Facility: Critical Point Facility (CPF)
Principal Investigator:
Dr. Hermann Klein
DLR Institute for Space Simulation
Cologne, Germany

Objective: The experiment is aimed at improved understanding of mechanisms by which heat flow and density stabilization occur in a fluid substance, particularly close to its critical point.

Science: Subjecting a fluid substance to any change, for instance a tiny addition of heat, results in effects such as the introduction of localized density variations. Assuming the system was previously in a stable state, this amounts to a temporary disruption, or imbalanced state. Then, a relaxation or smoothing-out process will occur as the localized differences dissolve and conditions adjust toward uniformity throughout the fluid. Scientists refer to such a process, which ends with the substance at stable conditions, as "equilibration." They are particularly interested in the detailed physical mechanisms by which such changes occur -- mechanisms which include thermal transport, or how heat is moved, and mass transport, or how matter is rearranged.

As an example of such a process, a fluid which is below its critical temperature consists of distinct gas and liquid phases. One can see a boundary, or meniscus, between the two. However, heating of the fluid -- causing it to pass through its critical temperature -- causes this visible boundary to disappear. The fluid has entered a new single- phase condition where the liquid and gas are indistinguishable. When conditions such as density and temperature have stabilized following the phase-change process, the fluid is homogeneous. Local imbalances will be present and the system will be in a non-equilibrium state until mass transport is able to achieve a balance among the areas of density in homogeneity. It takes time for the stabilization to occur; this time element is of particular interest to physicists.

An analogous situation occurs when a fluid sample is cooled from above to below the critical point. It starts as a single fluid phase and becomes separate, coexisting phases of gas and liquid with a distinguishable boundary between the two. However, it again takes time before the equilibrium densities of the two phases have become fully developed, and while this is going on, there is an associated redistribution of mass under way, or rearrangement of matter within the fluid.

Significance: The study of fluid systems is a fundamental area of physics and one of the key objectives in the fluid systems field is understanding of equilibration processes and times. Equilibration times are very significant for obtaining meaningful experimental results in the measurement of physical properties. Near the critical point, physical properties take on a remarkable nonlinear character, something which can only be fully assessed when equilibrium states and equilibration processes are thoroughly known.

This research is also expected to provide a better understanding of the behavior of fluids in rocket and spacecraft thruster reservoirs, of processes inside heat exchangers, and of cleaning methods involving fluids at high pressure.

Operations: Sulfur hexafluoride is also the sample fluid for this experiment, because it is chemically inert and reaches its critical point at moderate conditions. During experiment runs, the sample is subjected to precisely controlled changes of temperature, to produce subtle physical effects such as described above. In the Critical Point Facility, a laser beam is directed through the sample. The amount to which the light intensity diminishes after passing through the sample -- the degree of light attenuation -- is an indicator of

how close the sample is to the actual critical point, and also permits observing the progressive stages from disequilibrium to equilibrium and vice versa.

Crew involvement in the experiment consists primarily of unstowing and installing the dedicated experiment thermostat and powering up the laser and camera systems early in the mission. They will perform specific steps to initiate the experiment and verify that data is being properly gathered. After that, a combination of programmed commands and ground control inputs are used to cycle the sample through experiment runs.

Heat Transport and Density Fluctuations in a Critical Fluid

Experiment Facility: Critical Point Facility (CPF)
Principal Investigator:
Dr. Antonius Michels
University of Amsterdam
Amsterdam, The Netherlands

Objective: This experiment will measure the propagation of heat within a fluid near its critical point.

Science: Fluids reach their critical point when a precise combination of temperature and pressure compels their liquid and gas phases to become identical and form one phase. In this unusual state, the properties of the fluids can be altered dramatically.

One process of interest to scientists is how heat is transported within a critical fluid. There are three fundamental mechanisms which transport heat: propagation of sound, thermal diffusion and adiabatic compression heating, which is heating where there is negligible external input or release of heat. The latter two mechanisms are the focus of this experiment.

With liquids and gases, thermal diffusion is predominant. However, it becomes slower and slower as the fluid nears its critical point. Since fluid becomes increasingly compressible as it approaches the critical point, the compression heating becomes dominant in the near-critical state.

On Earth, heat transport investigations are flawed by gravity-driven convection. This space-based experiment allows scientists to study the relative importance of thermal diffusion and adiabatic compression heating in a convection- free environment.

Significance: Critical fluids are useful in technical applications such as extraction processes, where materials are transferred from low density to high density with very little force. Manufacturers must accurately calculate the feasibility of the technique for their specific process. If they are only a few percentage points off in these calculations, the process could be too expensive or inefficient to be practical. A better understanding of how heat transport mechanisms are altered near the critical point is important to improve the accuracy of these calculations.

Knowledge gained from this experiment will also improve scientific understanding of fundamental fluid physics.

Operations: A sealed canister containing sulfur hexafluoride will be placed in the Critical Point Facility by a crew member. Pre-programmed computer commands will begin the search for the critical point, which will be achieved at a temperature between 113 and 115 degrees Fahrenheit (45 and 46 !C). The sample will be heated to about three degrees higher than the critical temperature, then it will be lowered step by step Q two thirds of the difference, then two-thirds again, until the critical point is reached.

The experiment team will monitor density differences within the fluid via downlinked video images as the critical point is crossed several times. Motion of the density differences, along with readings from

temperature sensors within the sample container, will tell them how heat is being transported. A remote team in Amsterdam will receive simultaneous video and data, which they will process for more accurate understanding of the experiment.

Background: Dr. Michels performed a different experiment in the Critical Point Facility during the 1992 IML-1 mission. It helped confirm the effectiveness of the experiment facility for space-based investigations.

Vibration Isolation Box Experiment System (VIBES)

Payload Developer: NASDA

Objective: The Vibration Isolation Box Experiment investigates the effects of so-called "g-jitter," disturbances caused by crew movement and experiment equipment operations in space laboratories such as Spacelab. The information will be useful for experiment systems sensitive to the quality of the microgravity environment.

The experiment will test the effectiveness of a box designed to isolate sensitive experiments from vibrations caused by g-jitter.

Significance: The IML-2 mission has been designed especially to provide the highest quality microgravity environment available in the Space Shuttle. However, it is impossible to totally eliminate all disturbances to such an environment. Crew movements, equipment operations and occasional thruster firings can disrupt the quiet low-gravity environment and may affect some science experiments.

The Vibration Isolation Box Experiment System will support two experiments to study how g-jitter affects natural fluid flows, diffusion and thermally driven fluid flows under microgravity.

Both experiments will be performed with and without a damping system, to see how well the isolation box counteracts the effects of g-jitter on sensitive microgravity experiments.

Experiment Hardware and Operations: This system consists of a lockable vibration isolation box, two experiment units and an acceleration measurement unit.

Experiment units are placed inside the vibration isolation box inner container. The container is attached to an outer frame by a visco-elastic damping material. When the damping system is enabled, it should isolate experiments inside the box from some of the movements which would otherwise disturb them. Windows in the experiment units and the isolation box allow experiment operations to be videotaped.

The system has an acceleration measurement feature, consisting of two accelerometer sensor heads and a recording apparatus. One is mounted within the isolation box inner container, and another is mounted in the system's exterior framework, allowing accelerations to be measured both inside and outside the isolation box. After the mission, scientists can compare the acceleration measurements with fluid movement recorded on videotape.

Background: This experiment system is provided by the National Space Development Agency of Japan. A similar system was flown as an avian egg container in Spacelab-J to protect the egg from launch vibration.

Influence of G-Jitter on Natural Convection and Diffusive Transport

Experiment Facility: Vibration Isolation Box Experiment System (VIBES)
Principal Investigator:
Dr. Hisao Azuma
National Aerospace Laboratory
Chohu-shi, Japan

Objective: This experiment will measure the effects of disturbances on flow and diffusion in a liquid within the Shuttle. It also will study the ability of the Vibration Isolation Box Experiment System to isolate experiments from these disturbances.

Significance: Disturbances caused by crew movement and equipment operations, known as g-jitter, can interrupt the quiet microgravity environment needed for some space experiments. In most cases, these disturbances are unavoidable. Experience from previous missions has proved the value of having astronauts onboard a space laboratory to operate, observe and adjust experiments. Essential equipment operations, from the hum of experiment systems to the motion of the TV antenna that transmits signals to ground controllers, create disturbances as well.

This experiment will determine how much g-jitter influences natural convection and diffusion in a liquid, as it is heated from one side to create a fluid flow. The experiment will be performed with and without the isolation box damping system, to test how well the system counteracts g-jitter effects.

Operations: A crew member will set up the convection and diffusion unit inside the isolation box during a time when all seven astronauts are awake and active. The unit is a rectangular container filled with diluted salt water that includes indicator dye. Both the isolation box and experiment unit have observation windows.

One side of the container will be heated to create a temperature difference in the water. Flows caused by residual gravity in the Shuttle and g-jitter can be tracked by observing the colored dye, and live video of the fluid motion will be transmitted to ground controllers. The experiment then will be repeated with the isolation box suspended from the facility's outer frame, with a visco-elastic damper. Scientists will evaluate how much the damping system protects the experiment from external disturbances.

The system's acceleration measurement system will record motion detected by its sensors for later comparison with the video.

Study on Thermally Driven Flow Under Microgravity

Experiment Facility: Vibration Isolation Box Experiment System (VIBES)
Principal Investigator:
Dr. Masao Furukawa
NASDA Tsukuba Space Center
Ibaraki, Japan

Objective: This experiment studies the basis for a more efficient spacecraft thermal management system. It is planned to confirm the basic function of liquid transport mechanisms in space using the principle of differential vapor pressure.

Science: One method for managing excess heat is a two-phase fluid loop, which transports liquid that separates from the co-existing vapor in microgravity. This experiment will test the fluid-transporting characteristics of a device known as an accumulator -- comparing its performance with and without a mechanism designed to damp, or check, vibrations created by motion within the spacecraft.

On Earth, the system works well because water vapor rises to the top of the heated chamber, displacing some of the water to the other side. In microgravity, however, factors masked by gravity on Earth like the tension on the surface of the fluid will play a significant role in separating the fluid flow.

Significance: The next generation of spacecraft will be larger, more complex to operate, and will generate more heat. Therefore, their thermal management systems must have greater heat acquisition and rejection capability and be able to transport waste heat over a long distance. This study helps develop fluid management technologies such as gas and liquid separation, liquid reorientation, or liquid transport. Experiment scientists consider it indispensable for developing a two-phase fluid loop system, considered to be a primary candidate for future spacecraft thermal management.

Results also will contribute to the design of fuel cells, power plants, and environmental and life support systems which require thermal management of liquids.

Operations: A crew member will place the accumulator inside the Vibration Isolation Box, then heat the fluid on one side to observe the transfer process.

One experiment run will be completed without the isolation box damping mechanism engaged. For the other run, the isolation box will be suspended from the facility's outer frame with a visco-elastic damper. Behavior of the liquid flow and two-dimensional vapor/liquid diffusion will be recorded on video during both runs. Scientists evaluate how much the damping system protects the experiment from external disturbances.

The system's accelerometer will record motion detected by its sensors for later comparison with the video.

Space Acceleration Measurement System (SAMS)

Payload Developer: NASA
Principal Investigator:
Mr. Charles Baugher
NASA Marshall Space Flight Center
Huntsville, Ala.

Objective: The Space Acceleration Measurement System (SAMS) instrument will monitor and record higher-frequency onboard accelerations and vibrations experienced in the Spacelab module during flight. After the mission, scientists for IML-2 microgravity investigations will compare these records with their own data to identify accelerations which may have influenced their experiments.

Significance: Many of the IML-2 experiments require a very smooth ride through space so their delicate operations will not be disturbed. To maintain the most stable environment possible, the Shuttle will fly most of the mission with its tail 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 which disturb acceleration-sensitive experiments.

Even in a gravity-gradient attitude, though, accelerations caused by crew movements, equipment operations and occasional thruster firings can temporarily disrupt the quiet low- gravity environment and may affect microgravity science experiments.

Different kinds of disturbances show up at different frequencies. They are measured in terms of fractions of Earth's gravity. Accelerations at one frequency may interrupt one type of experiment but have no effect on others. By studying SAMS data, scientists can determine not only that a disturbance occurred but can be fairly certain what caused it. They can then make allowances for the disturbance as they analyze their experiment results.

Scientists' growing understanding of how various accelerations affect individual experiments is helping researchers improve equipment and procedures for future flights on the Shuttle and for Space Station operations.

Experiment Hardware and Operations: Three remote sensor heads, each measuring motion in three dimensions, are located near selected experiments within the Spacelab module. They measure accelerations as small as one-millionth of Earth's gravity. The signals are transmitted via cable links to a central control unit in the center aisle of the module, where they are amplified, filtered and converted to digital data for storage on optical disks. Each disk can store up to 400 million bytes of data.

The sensor located near the Bubble, Drop and Particle Unit measures frequencies in the range of 10 Hertz, the sensor next to the Critical Point Facility measures frequencies of about 5 Hertz, and the one near the Electromagnetic Containerless Processing Facility measures frequencies in the 100 Hertz range. These materials and fluids science experiments are particularly sensitive to the frequency ranges SAMS will record.

The crew will activate the SAMS experiment halfway through Flight Day 1, then change out optical disks daily as they are filled. The experiment operates continuously for the duration of the mission.

Background: Prior to IML-2, the Space Acceleration Measurement System flew on nine Shuttle missions, including IML-1 in January 1992. In addition to the information SAMS provides for other experiments, NASA has used its data to better understand the microgravity environment in different areas of the Shuttle. The instrument is provided by NASA's Lewis Research Center in Cleveland, Ohio.

Quasi-Steady Acceleration Measurement (QSAM)

Payload Developer: German Aerospace Research Establishment (DLR)
Principal Investigator:
Dr. Hans Hamacher
DLR Institute for Space Simulation
Cologne, Germany

Objective: The Quasi-Steady Acceleration Measurement (QSAM) experiment is primarily designed to detect steady, very low-frequency, residual accelerations between 0 and 0.02 Hertz. These disturbances to the Spacelab microgravity environment include tidal accelerations caused by variations in Earth's gravitational field, atmospheric drag, and the slow rotation of the orbiter necessary to maintain its orientation toward the Earth.

Significance: This experiment, along with the Space Acceleration Measurement System, will provide the IML-2 mission with the most effective acceleration measurement systems.

Nearly all the IML-2 experiments rely on the state of microgravity -- commonly known as weightlessness -- to accomplish their goals. However, various disturbances exist in a spacecraft which make it impossible to achieve complete zero-gravity conditions. These include rapidly changing movements, like those of the crew or periodic equipment operations; and steady accelerations such as the slight pull on the Shuttle created by atmospheric drag.

All experiments can tolerate a certain level of disturbance. But different experiments are sensitive to different types of accelerations. Scientists need to know the exact level of accelerations that occur during their experiments to correctly interpret their results. In the past, the whole range of accelerations could not be covered by one system. QSAM will fill in the gaps by measuring steady, low-frequency accelerations, which affect some physical processes more than higher frequency accelerations.

Experiment Hardware and Operations: This experiment uses four rotating sensor heads and three stationary sensors to measure residual quasi-steady accelerations. The stationary sensors record accelerations of up to 50 Hertz. To achieve reliable measurements in lower frequencies, the accuracy of the sensors must be tested, or calibrated, in orbit. The rotating sensors measure accelerations in one axis, then flip 180 degrees and measure them in another, ensuring the accuracy of the readings. They should be able to sense disturbances as small as one ten-millionth of Earth's gravity (10 -7), ten times more still than theoretical "microgravity" (10 -6).

Measurements will be recorded throughout the mission on optical disks. The crew will activate the experiment about 12 hours after launch and change out disks approximately once every two days. Otherwise, the experiment operates autonomously.

Background: IML-2 is the first flight for this experiment, and one of the first which will take measurements of steady, very low frequency residual accelerations. The Quasi-Steady Acceleration Measurement system was developed by the German Aerospace Research Establishment (DLR).

Biostack (BSK)

Payload Developer: DLR
Principal Investigator:
Dr. Guenther Reitz
DLR Institute for Aerospace Medicine
Cologne, Germany

Objective: Biostack is part of a multinational program to determine the impact of high atomic number, high-energy cosmic radiation particles on life in space. It uses radiation detectors enclosed between a variety of biological specimens to monitor particles entering the Spacelab module. The specimens will be studied post flight to locate the path and entry point of each heavy ion in the biological layer, and determine the extent of any changes or damage it may have caused to the organism.

Significance: Orbiting spacecraft operate in a complex environment of electromagnetic radiation, charged particles from solar and galactic radiation, and charged particles created by the interaction of galactic radiation with Earth's atmosphere. Previous experiments indicate that particles of high atomic number and high energy have potentially serious side effects on living organisms. These effects cannot be fully investigated on Earth, because the atmosphere filters out most of this radiation. Biostack will help scientists understand the importance, effect and hazard of these high- energy particles on various living organisms in space. This is important to development of space radiation forecasting systems which may be needed for longer space flights.

Experiment Hardware and Operations: Three sealed aluminum Biostack containers are mounted in a Spacelab rack. Inside the containers, layers of different biological specimens are placed between different types of detectors to measure incoming radiation. When cosmic particles pass through the Biostack, they deposit their high energies in the layers of radiation detectors and specimens. This allows scientists to locate the trajectory of each heavy ion in the biological layer and to identify the site of penetration inside the biological subject.

The experiment uses two different strains of shrimp eggs and salad seeds. After the mission, scientists compare any damage to the specimens with cosmic particle penetrations identified by the detectors. This helps them assess how specific amounts of radiation affect different types of life.

The experiment, which is entirely passive, will collect particles throughout the mission.

Background: Biostack has a long history in the space program. Similar instruments flew in the 1970s on Apollo 16 and 17 and the Apollo-Soyuz Test Project. This experiment, developed by the German Aerospace Research Establishment (DLR), has flown previously on three Spacelab missions: Spacelab 1 in 1983, Spacelab-D1 in 1985, and IML-1 in 1992. Results from the early missions demonstrated that high-energy particles can have serious biological effects on an organism, since complete cells can be damaged or destroyed. The ultimate consequences of such damage depend on the organism's ability to repair or replace the affected cell.

Extended Duration Orbiter Medical Project (EDOMP)

Payload Developer: NASA

Objective: The Extended Duration Orbiter Medical Project is designed to protect the health and safety of the crew during 12- to 17-day missions aboard the Space Shuttle. The series of investigations is designed to assess the medical status of the crew members and the environment in which they work.

Significance: As Space Shuttle missions become longer and as plans are made for extended stays aboard Space Station, it is essential to both understand the effects of weightlessness and radiation on space travelers and develop measures to protect them from harm.

Background: This medical project was developed by NASA's Johnson Space Center for missions where Extended Duration Orbiter equipment allows Shuttle flights to increase from the 7-to-10-day range to the 13-to 16-day flights.

The project is an umbrella designation for various activities designed to assess or protect crew health during long missions. Though elements of the project were included on earlier missions, it flew as a separate payload aboard the USML-1 Spacelab in 1992. IML-2 will be its second flight as a Spacelab payload.

For IML-2, the Extended Duration Orbiter Medical Project includes two experiments. The Lower Body Negative Pressure apparatus continues evaluation of a treatment to counteract orthostatic intolerance, the dizziness astronauts can experience as blood pools in their legs on return to gravity. The Microbial Air Sample tests air in the Spacelab and crew cabin for accumulations of airborne bacteria and fungi which may cause human illnesses.

Lower Body Negative Pressure

Experiment Group: Extended Duration Orbiter Medical Project (EDOMP)
Principal Investigator:
Dr. John Charles
NASA Johnson Space Center
Houston, Texas

Objective: The Lower Body Negative Pressure (LBNP) experiment evaluates the effectiveness of a treatment designed to counteract orthostatic intolerance, the "lightheadedness" astronauts sometimes experience when returning to Earth from space.

Significance: Without the force of gravity, astronauts' body fluids shift toward their heads and upper torsos. This shift is associated with other changes, such as fluid volume loss and altered control of cardiovascular functions. When space travelers return to Earth and "normal" gravity, body fluids are pulled back to the legs. Sometimes this creates a reduced blood flow to the brain when they stand up. In extreme cases, it could cause loss of consciousness. Treatments to counteract these effects protect the long-term health of the crew and ensure they will be alert for critical landing operations.

Background: LBNP was used on Skylab in 1973-4 to monitor loss of orthostatic tolerance in astronauts who spent up to 84 days in space. The current LBNP equipment first flew on STS-32 in 1990 as an independent payload. IML-2 will be its ninth flight.

Results from previous flights indicate that orthostatic intolerance can be countered by ingesting salt tablets and water while exposing the lower body to four hours of reduced pressure. This combined treatment has been shown to recondition the cardiovascular system for up to 24 hours. Spacelab-J tests on female astronauts indicated it is as effective on women as men, contrary to predictions based on bed-rest studies on the ground.

Operations: The primary equipment for the LBNP activity is a fabric bag in which a partial vacuum can be created. It encases the astronaut's lower body and seals at the waist. By slightly lowering the pressure within the bag, body fluids are drawn back to the lower extremities, mimicking the natural fluid distribution that occurs when a person stands up on Earth. This conditions the cardiovascular system to accept the ingested salt and water for reentry and improves orthostatic tolerance.

Two different procedures are conducted in the experiment. Four times during the flight, the LBNP device will be used to monitor the adaptation to space flight by Payload Specialist Chiaki Mukai and Payload Commander Rick Hieb. In these 45- minute "ramp" tests, the LBNP is gradually lowered and raised again. Measurements will be made of heart size and function by ultrasound cardiology, blood pressure and heart rate. Leg circumference will be measured before and after the sessions to determine the volume of blood in the lower body.

The day before landing, Hieb and Mukai will spend four hours with their lower body encased in the low-pressure bag. During the first hour of this "soak" treatment, they will drink water and take salt tablets. This combined treatment will pull fluids back into the lower body where they should remain for up to 24 hours. Scientists will evaluate the success of the treatment by examining cardiovascular data taken on Hieb and Mukai shortly after landing.

Microbial Air Sampler

Experiment Group: Extended Duration Orbiter Medical Project (EDOMP)
Principal Investigator:

Mr. Duane L. Pierson
NASA Johnson Space Center
Houston, Texas

Objective: The Microbial Air Sampler collects information on airborne contaminant levels in the Shuttle throughout the mission. Results from IML-2 will be added to data from previous flights to establish baseline microbial levels during missions of different lengths and to evaluate potential risks to crew health and safety.

Significance: Because certain microorganisms can cause allergic reactions or infections, maintaining acceptable air quality in "tight buildings" with little or no outdoor air is important to protect the health of people who inhabit those buildings. Spacecraft are the ultimate tight buildings, because the air supply is completely contained within the vehicle. In addition, particles that normally settle down onto the ground or other surfaces on Earth remain airborne in space.

Measurements of air quality taken before and after brief Shuttle missions suggest that inflight microbial levels are typical of those from crowded indoor environments. In the closed environment of the Shuttle, however, bacteria levels gradually increase during flight. This is not unexpected, since the Shuttle's air-handling system was not designed to remove airborne organisms.

If results show that levels of microorganisms increase during relatively long Shuttle missions to the point of becoming a concern, recommendations will be made to counter these effects with additional air-filtration devices.

Background: The Microbial Air Sampler first flew on the Spacelab Life Sciences-1 mission in 1991. IML-2 will be its eleventh flight.

Results from previous missions indicate that the low relative humidity in the Spacelab tends to reduce fungal propagation. Bacteria identified were those commonly associated with the human body, and the number tended to rise and then fall by the end of the mission. However, data collection on long-term missions is considered insufficient at this point to predict whether another rise in microbial particles may occur later in a long flight.

Operations: This experiment uses a hand-held, battery- powered air sampler. Air is pulled into the sampler by a motorized fan. Particles in the air are trapped within the device on plastic strips containing agar, a gelatinous material used to culture bacteria.

Crew members will insert an agar strip into the sampler, expose it to the surrounding air for two minutes to collect bacteria samples, then store the strip in a plastic bag for analysis back on Earth. They then will repeat the process with another strip, treated with a different solution to attract fungi microbes.

Astronauts will collect air samples from selected areas of the Spacelab, flight deck, or middeck near the beginning, middle and end of the flight. This procedure allows the number and type of airborne microorganisms to be identified over a relatively long Shuttle mission.

Slow Rotating Centrifuge Microscope
Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)

Payload Developer: German Space Agency (DARA)

Objective: The Slow Rotating Centrifuge Microscope, NIZEMI, facility will provide scientists with the capability to observe both living and non-living matter exposed to levels of gravity ranging from 10-3 g (one thousandth of Earth's gravity) to 1.5 g. Free from Earth's gravitational pull, investigators will be able to see how organisms react to different gravity levels, and learn more about their gravity- sensing mechanisms.

Science: For IML-2, living matter such as slime mold, *Loxodes*, Euglena, jellyfish, Chara, cress roots and lymphocytes will be examined to determine how gravity affects cells and unicell and multicell organisms. Also, to investigate the solidification process of non-living matter at different gravity levels, scientists will observe a two- component mixture of succinonitrile-acetone, a transparent material which solidifies like metal.

Significance: Some plants and animals have specialized cells or organs that are responsible for perceiving gravity. Gravity-sensing mechanisms work, along with light and chemical substances, to keep the living organisms oriented. In order to provide an ecologically sound environment for extended stays in space, scientists must know more about the effects of microgravity on both living and non-living matter.

Experiment Hardware and Operations: The NIZEMI facility consists of three 19-inch (48 cm) modules. The NIZEMI Experiment Module contains a support module and the rotating centrifuge. The support module includes a halogen lamp to illuminate the samples as they react to the gravity variations, an electric motor drive for the centrifuge and special locking devices for the centrifuge during launch and landing. A front panel of the control unit displays the status of NIZEMI and the required crew activities. The centrifuge module contains two observation units, a microscope and a macroscope. The microscope has magnification powers of 32x, 20x, 10x, 5x and 2.5x. The macrounit has a field of view of 30 mm X 40 mm

(about 1.2 by 1.6 inches) and a depth of focus of approximately 8 mm (0.3 inch). The samples, cameras and stages for moving and focusing the samples during the experiment are located in the centrifuge module.

The NIZEMI Control Module has a monitor, recorder, front panel and the electronics of the video system. The video system permits display and storage of video signals generated by the two cameras located on the centrifuge of the experiment module. These video signals will be merged with display data from the Experiment Control Unit.

During the mission, the control module will generate Spacelab closed-circuit television, record and display video signals, and select the camera signal (macro or micro) to be transferred to the monitor, recorder or Spacelab.

The experiment control unit has the display, keyboard, control electronics and power electronics. This module performs data acquisition for housekeeping and experiment data, controls the experiment flow and monitors the status of the NIZEMI facility.

Cuvettes are somewhat akin to slides used with a conventional microscope, and house samples from each of eight different experiment types. Once the sample is secured in the centrifuge module, the crew member will coordinate with the principal investigator on the ground to make sure the sample can be observed and recorded during the experiment run. Temperatures and centrifuge rotation are predetermined and controlled through the ECU.

Background: The NIZEMI facility will be used for the first time during IML-2.

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

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Ingrid Block
DLR Institute for Aerospace Medicine
Cologne, Germany

Objective: To add to the understanding of how a single- cell organism, the slime mold, senses gravity, and to attempt to locate the specific site at which this perception occurs.

Significance: When the slime mold (Physarum polycephalum) is on a vertical solid surface it moves downward when surrounded by air. On the same surface, this same slime mold would move upward when submerged in water. Scientists do not fully understand how or why the ectoplasm (elastic wall) of the slime mold accomplishes rhythmic contractions, although changes in response to light intensity and gravity have been documented on previous Space Shuttle flights.

Up to this point, investigators have not been able to pinpoint the specific site in the slime mold where it can sense and react to changes in gravity. By observing the behavior of the slime mold in the NIZEMI facility, scientists hope to be able to witness changes in the organism as it is subjected to different levels of gravity.

Operations: This experiment involves observing the single- cell organism, slime mold, as it is exposed to gravity ranging from 1.5-g to microgravity. After placing a videotape into the facility's video recording unit, the crew member will remove a selected slime mold cuvette from the incubator and place it in the NIZEMI centrifuge. Temperature and lighting are automatically controlled when the door is closed and locked by the crew member. Next, the crew member will focus on the sample slime mold and coordinate with the principal investigator on the ground. Once the scientist is satisfied with the location and quality of the sample view, NIZEMI will automatically process the sample.

Graviorientation in Euglena gracilis (Euglena)

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Donat P. Hder
Friedrich-Alexander-University
Erlangen, Germany

Objective: This experiment is intended to determine the lowest level of gravity which can be sensed by a simple plant organism called Euglena gracilis. This free-moving single- cell flagellate orients itself in the water in relation to gravity and light, to reach the best habitat for photosynthesis and reproduction.

Scientists hope to learn how the plant's structure changes in microgravity. Some of the Euglena aboard Columbia are expected to reproduce, splitting into two organisms. The principal investigator's team wants to study if these organisms, which develop entirely in microgravity, react differently from the cells carried into space. Simple organisms are easier to study than complex, so scientists expect to gain insight into Euglena's threshold of sensitivity to gravity. For example, higher multi-cellular plant life perceives gravity with an organelle located in the root tip. The signal has to be transferred to a different part of the root, which then reacts to gravity's location. In this simple plant, all three of these activities -- perception, transduction and reaction, take place within one cell. Possible experiments for future missions would determine how the single plant cell transfers and reacts to this information.

Significance: Results based on studies of this unicellular "primitive" organism are ideal for interpreting and extrapolating the behavioral responses in more complex organisms and even humans. Furthermore, these organisms are ubiquitous and responsible for the production of oxygen. They also serve as sensitive evaluators for ultraviolet energy and toxic pollutants, such as heavy metals, which affect the orientation mechanisms of the cells.

Background: This is the first Shuttle flight for the experiment, but it has been preceded by extensive work on the ground. However, one theory suggests that perceiving levels of gravity is a passive process. It is believed that the back of the unicellular Euglena is heavier, similar to a buoy in water, causing the cell to always swim upward.

Other scientists believe that sensing gravity is an active process where a gravity receptor senses the direction of the Earth's gravitational field and signals the organism to swim in the opposite direction. First, Euglena was exposed to small amounts of ultraviolet radiation which impaired its ability to sense gravity. Scientists believe if Euglena used the passive, physical process to sense gravity, it would swim upwards even when exposed to radiation.

Operations: Team members believe they can determine the gravity-sensing mechanism by establishing the minimum gravity level the plant cell can detect and show a reaction to.

The microorganism will be exposed to various levels of simulated gravity in five-minute- increments in the NIZEMI slow rotating centrifuge microscope. A sample carried onboard the Shuttle in a 1-g centrifuge is scheduled to be placed in the NIZEMI early in the mission. This will be a control sample to determine Euglena's "normal" threshold of sensitivity to gravity. The run will start at 0-g, gradually increasing to 1.5-g in five-minute-increments for one hour. Mid-flight, one sample will be placed in the NIZEMI for an experiment run starting at 1.5-g and gradually decreasing over one hour to 0-g. Other experiment runs conducted at the middle and end of the mission will begin at 0-g, gradually advancing to 1.5-g.

These experiments should enable scientists to assess how Euglena adapts to microgravity. Video images will be analyzed with specially designed software, during the mission and after Columbia lands, to determine precisely when the micro-organism starts to perceive the simulated gravity and if the pull of gravity is being sensed by a gravity receptor. A microscope for observing single cells is mounted on the centrifuge plate of the NIZEMI apparatus.

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

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Ruth Hemmersbach-Krause
DLR Institute for Aerospace Medicine
Cologne, Germany

Objective: This experiment will study the orientation, velocities and swimming tracks of the unicellular organism, *Loxodes* striatus, to determine the threshold levels at which the organism begins to perceive gravitational forces.

Science: Previous experiments have demonstrated how some unicell organisms use gravity for their spatial orientation. One such organism, known as *Loxodes striatus*, has a specialized structure, the Muller organelle, which may be responsible for the perception of gravity. By exposing *Loxodes* cells to increasing accelerations in NIZEMI and observing changes in cell behavior, scientists can better determine the threshold of gravity perception in these organisms.

Significance: Since these cells may work similarly to the inner ear of vertebrates, this information is necessary for scientists to better understand the underlying mechanisms by which living creatures sense gravity.

Operations: The crew member will load a videotape into the NIZEMI video recording unit. Next, the crew member will select a sample of *Loxodes* cells from the passive thermal conditioning unit and place it into the facility's centrifuge. When the door to the centrifuge is closed and locked, temperature and lighting are automatically controlled. The crew member will then adjust the microscope to properly focus on the *Loxodes*, coordinating with scientists on the ground to ensure the best available view. NIZEMI automatic operations will then take over, exposing the *Loxodes* cells to increasing levels of acceleration, or artificial gravity, while a magnified view of the organisms' behavior is provided by the combination microscope/video camera system.

After landing, the *Loxodes* cells will be examined at high magnification by electron microscopy to determine changes in the structure of the gravity receptor and obtain information on the biomineralization of single cells.

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

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Dorothy Spangenberg
Eastern Virginia Medical School
Norfolk, Virginia

Objective: This study of aurelia ephyra, a jellyfish, is intended to improve scientists' understanding of the effects of microgravity on the developmental processes of animals and the role that gravity plays in the developmental responses of organisms on Earth.

Science: Ten jellyfish will be used inflight during the IML-2 mission. Six Earth-developed ephyrae will be used to study behavior. Four ephyrae samples will be maintained in a microgravity environment and the other two will be maintained at 1-g, or simulated Earth gravity. Two jellyfish in microgravity will have no gravity-sensing organs (statoliths). These two will be exposed to different levels of gravity to determine their gravity threshold for normal behavior. Data will be obtained post-landing from inflight videotaping of some of the jellyfish experiments.

The remaining four jellyfish will be flown as polyps and be exposed to iodine during the flight, causing them to transform into ephyrae in space. Two of these jellyfish will be kept in microgravity and two will be centrifuged at 1-g in the NIZEMI. These jellyfish will be observed at regular intervals to compare the developmental stages of the ephyrae. Again, gravity thresholds will be determined by exposing the jellyfish to different levels of gravity and observing their behavior. The gravity receptors and muscles of the ephyrae that develop during flight will be examined after the mission to determine the presence and nature of any abnormalities.

Significance: This experiment will help scientists better understand the effects of microgravity on developmental processes of animals and the role of gravity in the behavioral and developmental responses of organisms on Earth.

Background: A related experiment flew on the Spacelab Life Sciences 1 mission in June 1991. Among other things, it confirmed that, even under microgravity conditions, jellyfish polyps undergo metamorphosis Q transforming into the free- swimming ephyrae. However, the behavior of the ephyrae was modified in microgravity, whether the metamorphosis occurred in space or on Earth. During space flight, the ephyrae did not orient themselves as they do on Earth, where they sink mouth-downward when they stop pulsing. Rather, these ephyrae circled or looped while swimming and froze when they stopped pulsing.

Operations: After loading a videotape into the facility's video recording unit, the crew member will remove a cuvette containing a jellyfish from middeck stowage, place it in a cuvette holder and install it in the NIZEMI centrifuge. The crew member will coordinate with the principal investigator before the centrifuge door is closed and the experiment begins to run automatically, exposing the jellyfish to varying levels of microgravity. Some of the jellyfish will be preserved for post-flight analysis.

Gravireaction in Chara Rhizoids in Microgravity (Chara)

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Andreas Sievers
Rheinische Friedrich-Wilhelms-University
Bonn, Germany

Gravireaction in *Chara* Rhizoids in Microgravity (Chara)

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Andreas Sievers
Rheinische Friedrich-Wilhelms-University
Bonn, Germany

Objective: This investigation will use the viewing capability of the NIZEMI facility to determine the threshold values and minimal amount of gravitational force necessary for rhizoids of the simple plant, Chara, to react to gravity and change their direction of growth.

Science: Chara is a type of green algae that attaches to the base or material to which a plant is attached and from which it gets nutrients (substratum) by single cells called rhizoids. These rhizoids, tube-shaped, root-like organs that grow only at the tip of the cell, have membrane-enclosed barium sulfate crystals (statoliths) which cause the rhizoids to shift toward the force of gravity when the cell is turned or tilted. On Earth, it has been impossible to determine when the rhizoids first become sensitive to gravity. Knowledge of rhizoid growth and structural organization will be combined with video recordings of microscopic views of statoliths still attached to the rhizoids.

Significance: This investigation will help scientists understand how sensitive these single cells are to gravity and how they adjust to variations in gravity levels. This experiment, along with the study of cress roots, will add to scientists' understanding of gravity-sensing mechanisms, which have been studied intensively on Earth and in space.

Operation: Video microscopy will be used to observe the behavior of these statoliths in microgravity. The statoliths will be exposed to microgravity of varying strengths and durations. A sample of rhizoids will be labeled by the actin- binding drug phalloidin to allow investigators to observe the microfilament system where the statoliths are suspended. The crew member will put a videotape into the NIZEMI facility recorder before loading a Chara cuvette into the centrifuge. The crew member will coordinate all adjustments to the microscope with investigators on the ground. This experiment will run automatically.

Gravisensitivity of Cress Roots (Cress)

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Dieter Volkmann
Rheinische Friedrich-Wilhelms-University
Bonn, Germany

Objective: This experiment will involve exposing chemically prepared samples of roots from cress plants to varying levels of gravity, to determine the lowest level at which the roots become sensitive to changes in gravity.

Significance: If we are to consider raising plants for food and oxygen in space, we must first understand how changes in gravity will affect plant growth.

Science: Seedlings of cress must sense gravity in order to survive. Previous experiments have shown that their roots are extremely sensitive to even short periods of exposure to gravity. After the samples have been subjected to gravitational stimulation in the NIZEMI centrifuge, they will be examined for indications of any resultant changes. Some of them will be preserved inflight for postflight examination with an electron microscope.

Future experiments with cress roots may reveal whether they can "remember" receiving tiny doses of gravity that may fall below their normal threshold doses.

Operation: A videotape will be placed in the NIZEMI centrifuge to capture the data from this experiment. Once this has been accomplished, the crew member will install a cress root cuvette and adjust the microscope to provide the best image possible during processing. This investigation is automatically controlled through the onboard experiment control unit.

Lymphocyte Movements and Interactions (Motion)

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Augusto Cogoli
University of Sassari
Sassari, Italy
Space Biology Group of ETH
Zurich, Switzerland

Objective: This experiment is intended to determine whether or not T- and B-cells (immune system cells) can contact each other in a weightless environment.

Science: The activation of T-and B-cells is based on the exchange of messages, through soluble factors called lymphokines, as well as through cell-to-cell contact. In this experiment, colorless, weakly motile cells produced in lymphoid tissue (lymphocytes) will be observed to determine if they can make contact in space.

Significance: These cell interactions are critical for many biological functions, such as antigen recognition by immune cells. Observing these cells away from the influence of Earth's gravity will help scientists better understand the natural workings of the cells. An understanding of how the immune system works in microgravity will also be important during extended stays in space.

Operation: These cells will be activated with concavalir-A and incubated in the 37 degree Celsius (about 98.6 degree Fahrenheit) Biorack facility. The crew will remove a lymphocyte cuvette from the incubation rack and place the sample in the NIZEMI facility. Adjustments to the microscope will be made and the experiment started. The crew will be watching the cells' movements and contacts through the facility's microscope and views of the cells will be downlinked to scientists on the ground.

Background: This new Biorack experiment, which has not flown before, uses the NIZEMI facility for observation. A recent sounding rocket experiment provided direct evidence of cell contacts, with movements of cells in microgravity being detected by microscopic observations.

Convection Stability of a Planar Solidification Front (Moni)

Experiment Facility: Niedergeschwindigkeits-Zentrifugen-Mikroskop (NIZEMI)
Principal Investigator:
Dr. Klaus Leonartz
Aachen Center for Solidification in Space (ACCESS e.V.)
Aachen, Germany

Objective: This experiment will use the NIZEMI facility to test a mathematical model for making predictive calculations of the onset of convection, a type of flow which is caused by localized density differences in a fluid, such as melted metal.

Science: Convection fluid flow changes the properties of the melt, as well as the resulting solid. The solidification process is influenced by gravity, the concentration of the mixture, temperature levels at which it is heated and cooled and the speed at which the liquid forms a solid.

Significance: Low-gravity experiments will help improve materials in the future as scientists begin to understand more about the solidification process. Many materials are produced from a melt. Commercially, the most important materials produced in this manner are metals, and the solidification process plays a key role in determining the resulting properties, such as strength and weight.

Operation: For this experiment, a two-component mixture of succinonitrile-acetone, which is transparent, will be used because it solidifies like metal. A crew member will place the cuvette containing the succinonitrile-acetone mixture into the NIZEMI facility. The transparent quality of this mixture allows the NIZEMI optical system to be used for observations of the solidification process as it occurs in low gravity.

Biorack

Payload Developer: European Space Agency

Objective: The effect of microgravity and cosmic radiation on isolated cells, tissues, bacteria, small animals and plants will be studied using the Biorack facility. A multi- user facility, Biorack was developed by the European Space Agency to permit scientists to conduct life sciences experiments in space.

For IML-2, Biorack will accommodate 19 experiments from seven European countries. While the hardware used in each study will be unique, all experiment specimens fit into containers stored within Biorack. About 200 experiment containers will carry chemicals and biological materials ranging from bacteria, mammalian and human cells, isolated tissues and eggs to sea urchin larvae, fruit flies and plant seedlings.

Significance: 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. Also, fundamental gravity-dependent processes on Earth can be studied in the microgravity environment where this force is reduced.

Background: The STS-65 flight will be the third Spacelab mission for ESA's multi-user facility. Biorack was used for the first time on the D-1 German Spacelab mission in 1985 and again on the first International Microgravity Laboratory mission in 1992.

Hardware: The Biorack configuration is smaller than for the previous missions. It is a single lab rack consisting of a glovebox, two incubators, two centrifuges, two stowage containers and a cooler. The thermo-electric cooler , which is connected to the Spacelab cooling water loop, was recently developed for the IML-2 mission.
The Biorack provides the crew with "laboratory" cabinets and work space. It contains modules which enable a wide range of biological experiments. Container racks and centrifuges are mounted on trays that slide in and out for easy access. Exposing duplicate samples to a simulated 1-g environment in the two centrifuges will help scientists differentiate between the influence of microgravity and other space conditions, such as radiation.

The glovebox of the Biorack is a class-100, particle-free, enclosed work area that provides safe conditions for the handling of materials. The glovebox keeps materials from floating across the Spacelab and keeps chemical fixatives confined. Crew members have the option of using gloves that extend into the sealed work area to handle specimens.

To enhance observation and documentation of samples, a still camera or a video camera can be mounted on the glovebox. The glovebox photo camera with a winder and a pneumatic shutter control can be installed to photograph objects inside.

Experiments are housed in sealed containers, a small Type I container, about the size of a deck of playing cards, and a larger Type II container, about three times the size of a Type I container. Each container can be fitted with a standard electrical connector to interface with power and data lines provided by Biorack. The incubators house 24 containers on static racks as well as 16 containers on two centrifuges that simulate Earth's gravity. The centrifuges can only hold Type I containers. They have a fixed speed of 107 rpm.

Five Shuttle middeck lockers are available for age- sensitive biological material and unstable chemicals. (Some of these lockers will be shared with the German NIZEMI facility.) To provide the necessary temperature environment during launch and landing, Passive Thermal Conditioning Units are used in the middeck area.

Operations: Biological specimens have to be transferred to Spacelab before being loaded onto the Biorack for experiment operations. The containers will be kept at +41 degrees Fahrenheit and +50 degrees Fahrenheit (+5 degrees and +10 degrees C). In-flight and during landing, NASA's Life Science Laboratory Equipment freezer provides -4 degrees Fahrenheit (-20 degrees Celsius) for containers carrying frozen specimens. In addition, flight samples are either cooled at 5 degrees Celsius or returned at ambient temperature for post flight analysis. Three hours after landing at Kennedy Space Center, the experiments stowed in the middeck during descent are returned to the principal investigators. Three hours later, frozen samples are returned for evaluation.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Augusto Cogoli
University of Sassari, Sassari, Italy, and
Space Biology Group of ETH, Zurich, Switzerland

Objective: This experiment examines how white blood cells recognize and respond to foreign substances that enter the body. These foreign proteins, derived from pollen, virus or bacteria, are called antigens. Antibodies attached to the surface of the white blood cells recognize these foreign proteins and attach to them, provoking an antagonistic reaction.

Science: The human body has white blood cells, known as T- cells, on standby. Each particular type is responsible for recognizing, and finally fighting, millions of different "invaders". When called upon, the T-cells divide and proliferate. The antibodies, or surface receptor molecules, ride piggy-back on the T-cell. These antibodies recognize and adhere to the antigens much like puzzle pieces fitting exactly together. The antibodies can be released into the blood stream to fight the infection or, when the antigen is attached to a cell, the T-cells make cell-to-cell contact, invading the antigens to destroy or inactivate them chemically.

Significance: Infectious diseases have long been identified as the leading culprits behind human death worldwide. This experiment investigates basic processes that contribute to the understanding of diseases and how the immune system responds to external triggers such as germs and chemical factors (mitogens). It will specifically study the T-cell activation after exposure to antigens. Scientists want to know if the activation mechanism of lymphocytes by their specific antigens is also altered in space as is known to occur from studies using mitogen-activated cells. If both activation processes show similar changes, then a common gravity-dependent step must be affected by the space environment.

Operations: Cultures of mouse lymphocytes have been refined to specific T-cells. Some of these samples will be exposed to antigens, then incubated for 72 hours. Other samples will be incubated with a mitogen. The response of the lymphocytes is detected by marking cell products with a radioactive tracer. Scientists can observe the presence of this tracer in exceptionally small amounts of cell products.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Augusto Cogoli
University of Sassari, Sassari, Italy, and
Space Biology Group of ETH, Zurich, Switzerland

Objective: This experiment will seek deeper insight into the complex mechanism of white blood cell activation, which is essential for immune defense.

White blood cells, or lymphocytes, multiply to fight infections or to heal wounds. Before these cells can fight foreign substances within the body, they must be activated and proliferate. The substance that can stimulate cell division is called the mitogen.

Science: Lymphocytes can detect invading organisms or chemicals because they are equipped with surface receptor molecules (antibodies). The genes for those receptors can be shuffled and varied to produce structures that match virtually any foreign substance.

White blood cells free-floating in a liquid medium, called a suspension culture, will be used. On Earth, white blood cells are non-adhesive cells, meaning they do not attach to any surfaces. In this experiment,

tiny plastic balls, resembling a fine powder, will be added to the suspension. They are called microcarrier beads. An interesting phenomenon which has been observed is that white blood cells adhere to the microcarrier beads. When they are growing on the microcarrier beads, the number of white blood cells activated more than doubles in microgravity. The inclusion of microcarrier beads increases the surface area available to the white blood cells to adhere to.

Significance: The power of the immune system to deal with infection is remarkable. However, the complexity of the immune response presents challenges to scientists and their attempts to decipher it. A deeper understanding of how the immune system responds to infectious agents is necessary.

An illustration of how this immune response works is that, on the cellular level, proteins situated on the cell membrane receive "passwords" from other cells flowing by. When a foreign cell or substance (antigen) is identified by these proteins, the white blood cells known as T-cells respond with production of specific substances (cytokines) which are controlled by the genes located inside the cell's nucleus. One step in this reaction chain seems to be gravity- dependent. Studying the process in orbit makes it possible to compare what happens in microgravity and under simulated 1-g conditions.

Background: A precursor experiment was Dr. Cogoli's investigation, "Lymphocyte Proliferation in Weightlessness," which flew on the Spacelab Life Sciences-1 mission in 1991.

Operations: Cells floating in a liquid called a 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)

Experiment Facility: Biorack
Principal Investigator:
Dr. Augusto Cogoli
University of Sassari, Sassari, Italy, and
Space Biology Group of ETH, Zurich, Switzerland

Objective: Cell-to-cell contacts are one way in which white blood cells, such as T-cells and B-cells, exchange messages. This experiment will study the mechanics of this communication process by making direct observations of this phenomenon using the NIZEMI slow-rotating centrifuge and microscope.

Samples that have been chemically fixed in previous space flights indicate that cell-to-cell communication is taking place. Scientists wonder how the cells find each other in microgravity. They will directly observe if it is a random or active motion process.

Science: Postflight microscopic evaluations have shown that clusters of cells are formed, and that they communication through the cellular membranes. Changing their shape allows the lymphocytes to move much like an amoeba and to find each other. Cell-to-cell contacts are important for the chemical exchange of information.

Significance: These cell interactions have a key role in many biological functions, such as immune cells recognizing disease-forming cells. Cell-to-cell contacts also are important for the exchange of chemicals which are a prerequisite for the human body's immune responses.

Background: A sounding rocket experiment has provided direct evidence of cell movements and contacts. The cell movements were detected by real-time microscopic observations.

Operations: Lymphocytes will be activated in the Biorack glovebox. They will then be incubated and transferred to the NIZEMI slow rotating centrifuge microscope. Crew members will observe the samples using that facility's specialized microscope at three different times during the mission.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Didier Schmitt
Medical School Rangueil
Toulouse, France

Objective: The efficiency of activation of white blood cells, such as T-lymphocytes and monocytes, will be studied by measuring the production of substances that promote cell division. Cytokines, the production of which is inhibited in microgravity, are necessary to promote activation and proliferation of immune cells to fight disease. Investigators will measure the production of specific cytokines interleukin-1, interleukin-2 and gamma-interferon.

Science: Immune cells are those which help the body resist infection. Lymphocytes and monocytes, two types of immune cells, can be activated to produce cytokines, which in turn are necessary to activate other cells of the immune system. Monocytes can be activated by either adding synthetic growth- promoting factors such as phorbol esters or by increasing the intracellular calcium concentration. This is achieved by adding a specific calcium transport molecule to ease the calcium import to the cell. In contrast, T-cell lymphocytes need both of these methods simultaneously to be activated.

Significance: Previous space experiments have shown that the absence of gravity is interfering somewhere in this reaction chain. Scientists hope to determine which part of the reaction chain is altered in microgravity. They believe the information is being received by the cell, but the cell is not responding by dividing, as it normally would on Earth.

Operations: Cells are incubated in microgravity and on the 1-g centrifuge. About 15 hours after activation, cultures are filtered, the culture medium isolated, and cells are inactivated by a detergent. Postflight, scientists will compare the synthesis of different proteins in the cells and the culture medium will be examined for cytokines. If the medium contains these substances, scientists know that the nucleus was activated and responded properly by creating new cytokines. In addition, they will measure sugar consumption in the culture medium to determine the rate of cell growth and multiplication.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Didier Schmitt
Medical School Rangueil
Toulouse, France

Objective: Immune cells can be activated to divide through the binding to a receptor of an artificial cell growth- promoting factor called phorbol ester. The phorbol ester crosses through the cell membrane to reach the receptor located within the cell. This receptor is an enzyme called protein kinase C (PKC). The phorbol ester attaches to the receptor much like two puzzle pieces fitting together.

If the ester does not bind to the proper protein receptor, cellular maturation slows down or the cells do not multiply. Investigators will use a radioactively marked phorbol ester to measure first if the ester joined to the PKC and, second, to see if the message was transmitted to the internal part of the cell.

Science: Previous experiments in microgravity have shown that microgravity dramatically reduces cells' maturation and proliferation. A related experiment on the Soviet satellite Biocosmos 2044 showed a decrease in the secretion of cytokines, that promote cell division of immune cells. Cytokines are proteins which serve as messengers between cells of the immune system.

Significance: Scientists believe the "activation" information is being received by the cell in microgravity, but the cell is not responding by dividing, as it normally would on Earth. Phorbol ester, a growth promoting factor, will be used to activate the lymphocytes. Scientists want to determine what is preventing the cell from multiplying. Then, they may be able to develop a synthetic drug to duplicate what is happening in the absence of gravity and be able to inhibit the free multiplication of cells, such as cancer cells.

Operations: For this study, lymphocytes will be incubated in microgravity and in simulated gravity on a Biorack centrifuge. During this time, the radioactively marked phorbol esters can bind to their receptors. 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)

Experiment Facility: Biorack
Principal Investigator:
Dr. Philippe Bouloc
CNRS Jacques Monod Institute
Paris, France

Objective: Previous space flight experiments have indicated that the membranes of animal cells may have altered permeability properties in microgravity. It also has been suggested that bacteria may be more sensitive to antibiotics in microgravity. This experiment is designed to test possible changes that take place in bacteria during space flight. Scientists will observe cell response to a natural stimulus (carbon dioxide gas) and an artificial one (sodium chloride). They will study the effect of the absence of fluid convection and gas exchange on cell growth.

Science: A non-infectious strain of Escherichia coli bacteria will be used. Thermal and gravity-driven fluid convection (fluid flows) are essentially absent in microgravity. Therefore, carbon dioxide gas produced during respiration is expected to remain concentrated in the direct environment of the bacterium, resulting in growth stimulation. This time frame will be measured.

How the cell responds to an artificial change in its environment -- the addition of a salt solution -- also will be observed. Using a "sensor" protein located in their outer membrane, cells can detect changes in the osmotic pressure of the fluid surrounding them. This is the pressure at which a dissolved substance attempts to make its way through a membrane, by means of osmosis. The bacteria respond in a number of ways, one of which is to produce an enzyme. Changes in the cell membrane would be likely to affect the transfer of information. Scientists anticipate that the bacteria will react to the salt solution in some way to retain its intracellular fluid.

Significance: If membrane alterations are detected in bacterial cells cultivated in microgravity, it will reinforce the interpretation of earlier findings using animal cells by indicating that the phenomenon is quite general, covering the entire range of life forms.

The investigation also will provide a convenient model system for studying the changes within the cell's membrane, which may involve the absence of convection in microgravity. An understanding of the phenomenon may, in turn, permit specialists to avoid possible undesirable effects of membrane alterations on astronauts.

Operations: The crew will inject glucose into bacteria suspensions, which should begin their growth and multiplication process. When the growth has started, some of the cultures will be injected with a salt solution to increase the osmotic pressure. Finally, an antibiotic will be injected to halt the growth process, but not kill the cells.

After Columbia lands, scientists will measure how much growth actually took place between the injection of glucose and the antibiotic injection. They also will observe if a particular enzyme was produced in response to the presence of the salt solution.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Augusto Cogoli
Space Biology Group of ETH
Zurich, Switzerland

Objective: This technology experiment studies the effect of stirring and mixing on the growth characteristics of baker's yeast in microgravity. The growth of baker's yeast is directly related to the consumption of nutrients, such as glucose and oxygen. Investigators will determine if stirring the solution increases the amount of growth that takes place because the cells are continually being redistributed.

Scientists also will measure the threshold where the yeast solutions change from normal growth into the production of alcohol, which is a critical part of the experiment.

Significance: This experiment may have broad implications for future life science experiments. The phenomena discussed here imply that a 1-g reference centrifuge aboard space laboratories is not necessarily an optimal control for all types of space experiments. Rather, stirring or mixing to achieve a homogenous reaction mixture of cells and solutes may be better suited. On a future mission, it will be desirable to study if there is any difference when this solution is stirred while in simulated gravity on a centrifuge. This would show if a centrifuge itself is a proper method to simulate gravity for reference experiments in space.

Science: On Earth, most cells in cultures sediment and form pellets if they are not mixed. Cells within these pellets on the bottom of the container 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. An analogy would be the addition of chocolate to milk. On Earth, the chocolate sinks to the bottom. In microgravity, the chocolate and milk molecules hang side-by-side. Stirring the solutions might achieve a homogenous mixture, similar to mixing the chocolate syrup into the milk.

Operations: The yeast cells are contained in two special bioreactors; each fits into a Biorack Type II container and has a reactor chamber, a reservoir for nutrients and waste, mechanical components and electronics. Three milliliters (0.1 fluid ounce) of yeast culture is incubated in the reactor chamber. Fresh nutrient medium will be pumped at constant flow rates from the reservoir bag to the reaction chamber. The flow rate will be increased step by step to observe when the yeast switches from respiration to fermentation and begins forming alcohol.

Cells and medium will flow out through a one-way valve into the waste reservoir so that the volume of the culture remains constant. Experiment parameters of the chamber are controlled by a microprocessor, resulting in a stable environment. The bioreactor will run automatically for eight days, and data will be transmitted to the ground.

The crew will remove samples on specific days throughout the mission to determine if the yeast is expanding. The samples will be preserved for postflight analysis.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Uwe Heinlein
Heinrich-Heine University
Dusseldorf, Germany

Objective: This experiment will evaluate whether organized tissues can be reassembled from single primary cells in microgravity. If the cells reassemble, or aggregate, to form organized, tissue-like cell layers, microgravity could be the key to learning how cells recognize one another and interact to form specific patterns.

Science: As organisms develop from embryos, the many tissues which form must recognize like cells and group to form the various parts of the organism. On Earth, the processes of cellular recognition are difficult to study outside the body in cell cultures. Gravity disturbs the cell surface interactions necessary for optimal 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.

As gravity will not interfere with aggregation in space, the most likely influence will be molecular characteristics of the cell surfaces. Different cell samples are being flown with various types of adhesion molecules on their surfaces. Comparisons after the mission will help determine how cell surface structure influences aggregation.

Significance: Increased knowledge of how cells recognize one another to form tissues can be applied to overcoming problems related to tissue formation on Earth. For instance, some couples have difficulty conceiving children. One reason could be that the sperm does not recognize the egg, so fertilization cannot take place. If scientists can learn how cells communicate with one another, they might eventually be able to improve or prevent fertilization in humans.

Background: This experiment has not flown in space before.

Operations: This Biorack experiment will use primary cells prepared from two mouse tissues, brain cells from cerebellum and sperm-forming cells from testis. There are only five different kinds of cells in each tissue, making the tissues simple to study. Cells from the two kinds of tissues will be mixed before the experiment begins, to evaluate how well they can recognize like cells to aggregate into tissue over the course of the experiment.

Two containers with 10 cell cultures each will be placed in the Biorack incubator, one in microgravity and one in simulated gravity. A crew member will feed the cultures inside the glovebox on days two, four and six, by injecting a medium into the cell cultures. Growth will be chemically stopped, or fixed, on day six, and the containers will be stowed for the remainder of the mission. They will undergo postflight structural and chemical analysis.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Siegfried de Laat
Netherlands Institute for Developmental Biology
Utrecht, The Netherlands

Objective: This experiment will study the effect of microgravity on mouse cell differentiation which has been induced by exposure to retinoic acid, a Vitamin A group acid. Cell differentiation is the process by which embryonic cells divide to form into the different types of cells which make up an organism.

Science: This experiment is one of several aboard IML-2 examining early cell differentiation and growth. The ability to "turn off the gravity" in space gives scientists a valuable tool for studying cell differentiation processes without introducing chemicals or other materials inside the cells themselves.

It has been known for a decade that the removal of gravity affects early cellular development, for instance that of the immune system's lymphocytes. Sounding rocket experiments have established that the change does not take place on the surface of the cells. Therefore, it must happen at some point farther along in the reaction chain of cell development. The various IML-2 cellular experiments are attempting to identify that point.

Mouse cells serve as a model for cellular behavior in other animals and in humans. Retinoic acid has a profound effect on their early differentiation, particularly on the pattern in which the limbs form. This experiment will investigate where the gravity-dependent step is located in the reaction chain of cell response to retinoic acid. It also will study how the mouse cells multiply after exposure to the retinoic acid in microgravity.

Significance: Identifying the stages in the reaction chain of early cellular development would provide a valuable tool for fighting a multitude of diseases.

Background: IML-2 is the first flight for this Biorack experiment

Operations: Sixteen containers housing two culture chambers each will be processed for this experiment. On the second day of the mission, a crew member will load them into the Biorack incubator, in the microgravity rack and the simulated-gravity centrifuge. There, they will be processed through a pre-programmed, automatic experiment sequence for seven days. Experiment controllers on the ground can verify that each event has occurred on schedule by viewing data transmitted from the Biorack facility.

After medium exchange, activation and fixation are complete, the crew will transfer 10 of the containers to the Biorack cooler and the rest to middeck stowage for return to Earth and subsequent analysis.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Hans-Jurg Marthy
CNRS Observatoire Ocanologique
Banyuls-sur-Mer, France

Objective: This experiment studies sea urchin embryos and larvae to determine if the mineralization process that creates the typical sea urchin larva skeleton is normal in space.
Science: This is one of several experiments aboard IML-2 which researches the mechanisms involved in bone demineralization in weightlessness.

Previous tests of astronauts and small organisms have shown the lack of gravitational force on bone causes demineralization, the loss of calcium and other minerals. Although calcium loss may level off during space flight, the possibility that crew members could break weakened bones may affect their ability to function in Earth's gravity after an extended mission.

Significance: If this experiment finds there is a progressive loss of calcium and other minerals in the formed skeletons of sea urchins, that demineralization might be a good model for the loss of bone minerals experienced by humans in microgravity. Knowledge of the factors which govern bone demineralization could be applied to fighting disorders experienced by people on Earth such as osteoporosis, as well as helping protect space travelers.

Operations: A crew member will p lace containers with sea urchin eggs at two different stages of development in the Biorack incubator, in microgravity and in the gravity-simulating centrifuge. Several times during the mission, an astronaut will use the Biorack glovebox and a camcorder to make microscopic videotapes of swimming specimens.

Sea urchin larvae from all containers will be preserved at different stages of development. After the mission, scientists will analyze the preserved skeletons to assess their mineral composition and content.

Background: This Biorack experiment has not flown before.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. J. Paul Veldhuijzen
Amsterdam Academic Center for Dentistry
Amsterdam, The Netherlands

Objective: This experiment will attempt to verify recent indications that exposing cultured fetal mouse bones to simulated gravity during space flight can prevent microgravity-related bone loss. Scientists want to see if exposure to a short period of gravitational force during each day in space would be sufficient to prevent adverse microgravity effects on the skeleton.

Science: Tests on astronauts and small organisms during previous space flights indicate that the lack of gravitational force on bones causes demineralization, the loss of calcium and other minerals. Scientists are still researching whether this calcium loss continues indefinitely or levels off during flight. If it continues, the

likelihood that crew members will break those weakened bones increases the longer a mission lasts. Significant calcium loss also affects a person's ability to function in Earth's gravity after landing.

It has been shown that exposure of cultured fetal mouse bones to reduced gravity during space flight increased calcium 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 in humans.

Different cells govern bone mineralization, the input of calcium into the bones, and demineralization, or calcium export. In childhood, the input is greater, stimulating bone growth. The two processes reach a state of equilibrium in adulthood. Export cells become more dominant as a person or animal grows old, causing bone deterioration, or osteoporosis. This experiment will attempt to identify how much of the calcium loss in microgravity is due to a repression of mineralization and how much is caused by an acceleration of demineralization.

Results of this experiment on IML-1 showed a significant increase in calcium loss in the microgravity samples as opposed to those in Biorack's simulated-gravity centrifuge, suggesting that exposure to artificial gravity counteracts bone deterioration. The IML-2 experiment will expose embryonic mouse long bones to varying durations of simulated gravity to determine how much exposure is needed to deter calcium loss.

Significance: Exercise which stresses astronauts' bones in space, much as the pull of gravity stresses them on Earth, has been shown to be effective in counteracting calcium loss. Information gained from this experiment could eventually be the basis for determining how much, or how little, exercise is necessary for it to be a useful countermeasure.

Bone demineralization is an integral part of the aging process. Insights into basic bone building and destruction processes are useful in fighting bone disorders on Earth such as osteoporosis, which affects a large percentage of elderly people.

Background: This experiment flew in Biorack on IML-1 and on the Russian Biocosmos satellite. The indications were that both bone mineralization and demineralization are influenced by microgravity.

Operations: Four cell culture containers containing fetal mouse long bones will be processed in the Biorack incubator in microgravity. One will be put into the simulated-gravity centrifuge, where it will remain for the duration of the experiment. Between the first and fourth flight days, three of the microgravity containers will be exposed daily to three, six and 12 hours of simulated gravity, respectively. Then all the samples will be chemically fixed to stop growth. Scientists will analyze the samples after the mission to determine how exposure to various levels of gravity affected bone growth and deterioration.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Roberto Marco
Independent University of Madrid
Madrid, Spain

Objective: This experiment will study the development of fruit flies to test a theory about why the aging process of adult flies is accelerated in space.

Science: This experiment is one of several IML-2 investigations which attempts to determine if organisms can develop normally in space.

Previous experiments have shown that the exposure of young fruit flies to microgravity results in numerous effects on their development. These include an increase in the formation of eggs and an increase in the time required to complete the development process. However, the aging process of adult flies in these experiments has been accelerated.

During this long-duration flight, scientists will test an hypothesis that life shortening in space is linked to increased activity as the flies attempt to move in microgravity, along with excessive respiration. This ultimately results in damage to the part of the cell that provides energy to the cell by the respiration process.

Significance: Because the life span of flies is relatively short, almost their entire aging process can be studied during a Shuttle mission. Insights gained from this experiment could prove to be useful models in studying the factors which influence aging in humans.

Background: In a 1985 Spacelab D-1 experiment, investigators observed that the aging process was accelerated in flies exposed to microgravity. When this experiment flew on the Russian Biocosmos satellite, video of the flies' movement showed that their activity levels were greatly increased. An almost identical experiment flew on Biorack during IML-1 in 1992. However, the flies did not survive the flight. A small hole covered with a fine nylon mesh has been added to the fly containers to supply them with fresh air.

Operations: Fruit flies will be flown in space within the Biorack facility, both in microgravity and in the simulated gravity of the centrifuge. Activities of male flies will be recorded by video observations periodically throughout the mission. Embryos deposited by female flies will be frozen on specific days to preserve them for postflight analysis.

After the mission, the preserved embryos and live adult flies will be studied. Scientists will examine the flies' physical characteristics, biochemical makeup and behavior to determine the effects of microgravity on the genetic background, development processes, sexual behavior, orientation to gravity and aging.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Geertje Ubbels
The Netherlands Institute for Developmental Biology
The Hubrecht Laboratory
Utrecht, The Netherlands

Objective: This experiment examines the early stages of frog egg cell division, to determine the role gravity plays in directing cell division and differentiation as the cells form a new organism.

Science: Before space flight, organisms always developed with reference to gravity. Scientists are just beginning to study whether normal offspring will result when organisms mate and reproduce in space. This experiment will help them determine how organisms reproduce and develop without gravity. It also will give them greater insight into gravity's role in these processes.

On Earth, the eggs of clawed toads rotate shortly after they are fertilized, with a selected pole oriented downward toward gravity. Previous experiments suggest that gravity cooperates with the sperm in specifying the correct orientation, or axis.

The time and pattern of subsequent cell divisions are crucial in this early stage of embryonic pattern formation. At first, the cells divide almost in the same way at the same time. At later stages, this synchrony

is progressively lost, making a “wave” of cell divisions over the egg. The cell population splits into compartments, each with its own division rhythm that corresponds to areas for later development of the organs, bones, etc. This experiment examines whether normal division synchrony in the early embryo is maintained under microgravity.

Significance: Insights into the early stages of cell development can serve as models for understanding the factors involved in normal development from a single cell to a complete organism.

Background: During a brief sounding rocket flight prior to the 1992 IML-1 mission, this experiment demonstrated for the first time that fertilization can take place in microgravity. Embryo development in space went on much longer during the IML-1 Shuttle flight. Postflight analysis of those embryos showed an irregularity in the thickness of cell layers at one stage of cell division.

A related experiment flew on Spacelab-J later in 1992, where eggs of live frogs were fertilized in space. The resulting embryos developed normally, indicating that any irregularity in cell formation due to microgravity was repaired during later stages of development. The IML-2 experiment will attempt to isolate the specific point at which the irregularity occurred.

Both IML-1 and Spacelab-J experiments indicate that gravity is not responsible for the orientation of the cell axis. This experiment will help confirm those results.

Operations: A crew member will place identical samples in Biorack’s two incubators, with four samples in microgravity and two in the simulated gravity of a Biorack centrifuge. At the same time, identical samples will be incubated on the ground. Frog eggs will be fertilized within a microprocessor-controlled culture vessel. Samples from each test environment will be fixed to stop growth on the fourth and eighth cleavage, or cell division step, and in a later stage of embryonic development.

Postflight, samples from microgravity, simulated gravity in space, and Earth’s gravity will be compared. The pattern of cell divisions, as well as the distribution of cellular constituents, will be determined in relation to axis formation.

Effect of Microgravity on Lentil Morphogenesis (Lentil)

Experiment Facility: Biorack
Principal Investigator:
Dr. Grald Perbal
Pierre and Marie Curie University
Paris, France

Objective: The purpose of this experiment is to test a theory about how the gravity-sensing cells at the tip of plant roots regulate root growth.

Science: Gravity sensing cells called statocytes are found in a cap covering the plant root tip. The sub-cellular components are arranged within these cells with respect to gravity. The nucleus is always located in the top part, and membrane-enclosed crystals of barium sulfate, called statoliths, congregate on the bottom. When the root is placed in a horizontal position, the statoliths move toward the longitudinal wall but never touch the plasma membrane. It is generally accepted that the statoliths are responsible for sensing gravity, but the way they do that is still controversial. This experiment tests the hypothesis that the settling down of the statoliths on the endoplasmic reticulum, a web-like structure within the cell protoplasm, regulates root growth.

Significance: Scientists are still investigating which direction plant roots will grow when there is no distinguishable up or down, as is the case in the weightless environment of space. Researchers also want to know if root growth is inhibited by changes in growth direction. These questions must be answered before plants can be grown as part of a controlled ecological environment needed for long-term stays in space.

Equipment and Operations: In this IML-2 experiment, six different groups of lentil seeds will be exposed to both microgravity (after germination on the 1-g centrifuge) and 1- g environments. The seeds will be hydrated with water or cytochalasin B in the Biorack glovebox on day 10 of the mission and transferred to the 22 degree Celsius (72 degrees Fahrenheit) incubator. After one day of growth, the seedlings will be photographed with the glovebox camera. The principal investigator on the ground will observe the seedlings via television and will talk with the crew to confirm the correct growth status. The seedlings from the centrifuge will be returned to incubate in the static rack and those in the static rack will be placed on the centrifuge. The seedlings will be photographed again two hours later (also with video downlink) and fixed (preserved with glutaraldehyde) for analysis after the mission.

Background: This experiment is nearly identical to the "Roots" experiment flown on IML-1. It uses the same hardware, biological samples and chemicals, with the addition of mini-syringes containing cytochalasin B for IML-2. Results from the IML-1 Roots investigation show that plant roots were sensitive to periods of alternating gravity and microgravity. However, scientists do not fully understand how changes in the growth direction of these roots will affect overall growth.

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

Experiment Facility: Biorack
Principal Investigator:
Dr. Tor-Henning Iversen
University of Trondheim
Dragvoll, Norway

Objective: This experiment will test whether the growth of plants that grow in any direction apparently unaffected by gravity (agravitropic roots) on Earth is similar to normal roots grown in microgravity.

Science: Three clones of transformed, agravitropic roots have been isolated. Normal gravitropic roots, which grow downward, will be used as the control subject specimens for this experiment. In addition, single transformed cells which have been isolated from these roots will be tested. These cells will be isolated as protoplasts (cells from which the cell walls have been removed). After the mission, scientists will attempt to regenerate intact plants from the protoplasts.

Significance: Transformation of plant cells by strains of a bacteria known as *Agrobacterium* causes dramatic changes in the metabolism of the transformed cells and the physical characteristics of the intact plants regenerated from the transformed cells. Wild type strains of *Agrobacterium rhizomes* are known to induce transformed roots called "hairy roots." These roots have a high growth rate, branch out excessively and, in some cases, do not exhibit curvature in response to gravity (gravitropism). Scientists must learn more about plant growth in microgravity before plants can be included as part of the ecological environment system for longer stays in space.

Experiment Hardware and Operation: The plant chambers for this experiment are made of aluminum frames with clear windows to allow for photography. The protoplast cultures will be in plastic bags, heat-sealed at one end, with a sterile seal (septum) at the other end.

During IML-2, containers with root segments will be incubated at 22 degrees Celsius (72 degrees Fahrenheit). At selected times, the plant chambers will be exposed to 1-g, placed in the photobox for

automatic photography, fixed (preserved with glutaraldehyde) in the glovebox, and stored in the Biorack cooler. The protoplast cultures will undergo incubation (in both microgravity and 1-g), fixation, washing with a buffer and cooling.

Background: This is a new Biorack investigation that has not flown before. However, the hardware is similar to the Roots and Proto experiments flown on IML-1. The photobox is identical to that flown on IML-1, but the sample holder has been modified to accommodate experiments for IML-2.

Plant Growth and Random Walk (Random)

Experiment Facility: Biorack
Principal Investigator:
Dr. Anders Johnsson
University of Trondheim
Dragvoll, Norway

Objective: This experiment will observe root behavior in a weightless environment, with the aim of increasing our knowledge of root growth dynamics.

Science: Experiments on Earth have shown that plants exposed to gravity levels higher than 1-g grow in a more "straight" fashion. Changes in the normal growth patterns are caused by spontaneous random movements and the nature of these movements can only be studied in an environment free from Earth's gravitational pull.

Scientists have hypothesized that the random movements can be described and treated as a "random walk" process (similar to the random motions of molecules in a liquid). This hypothesis will be tested in the weightless environment of space during IML-2. Although photographs will provide the main source of information from this experiment, samples will be fixed (preserved with glutaraldehyde) and returned to Earth for analysis.

Significance: A quantitative study of root behavior in space will test the random walk hypothesis and increase our knowledge of the dynamics of root growth. Research such as this 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.

Operations: Lepidium sp. seedlings, which are housed in plant chambers with clear windows, will be transferred to a photobox at about 11 and 17 hours into the mission. Time-lapse photography will be performed over a 35-hour period. Other containers of seedlings will be exposed to 1-g on the centrifuge inside the 22 degrees Celsius (72 degrees Fahrenheit) incubator for 18 and 20 hours and will then be transferred to the photobox to provide visual documentation of their growth patterns.

Background: This is a new Biorack experiment that has not been flown before. It is**,** however, similar to the "Roots" experiment flown on IML-1. The photobox is identical to the one flown on IML- 1, but the sample holder has been modified to accommodate this experiment and the mirrors have been removed.

Dosimetric Mapping Inside Biorack on IML-2 (Dosimetry)

Experiment Facility: Biorack
Principal Investigator:
Dr. Guenther Reitz
DLR Institute for Aerospace Medicine
Cologne, Germany

Objective: This investigation is designed to provide a baseline of radiation data for all Biorack scientists to use when analyzing their respective experiment results.

Science: This information is a precondition for any investigation in space that might be susceptible to radiation. In order to provide scientists with a good baseline of radiation information, this experiment will document the radiation environment inside the Biorack facility and compare the data with theoretical predictions and data from previous flight experiments.

Significance: From the data collected during this experiment, principal investigators will be able to distinguish microgravity effects from radiation effects on samples that were placed in the Biorack facility. Although the Spacelab module has special radiation shielding, cosmic radiation does penetrate the spacecraft. Previous investigations have shown that radiation can be particularly damaging to single cells. Scientists must be able to predict and measure the influence of cosmic radiation when determining flight parameters and the amount of shielding needed to conduct experiments in space.

Equipment and Operations: Each of the seven dosimeters contains three types of visual track detectors with various layers of cellulose nitrate, Delrin, Kapton foil and nuclear emulsion. Before launch, dosimeters will be placed in the 22-degree Celsius (72 degrees Fahrenheit) and 37-degree Celsius (99 degrees Fahrenheit) incubators; one will be loaded into the Biorack cooler, one into the Biorack stowage, one to overhead stowage, and the remaining two will be kept in ambient stowage.

Background: This experiment is identical to the investigation of the same name that flew on IML-1. For IML- 2, all experiment hardware has been newly fabricated. Results from IML-1 showed that radiation in the two Biorack incubators was similar. By placing additional dosimeters in other areas of the Biorack facility, scientists will be able to see if radiation levels are different throughout the facility.

Efficiency of Radiation Repair in Prokaryotes (Repair)

Experiment Facility: Biorack
Principal Investigator:
Dr. Gerda Horneck
DLR Institute for Aerospace Medicine
Cologne, Germany

Objective: This experiment will test the hypothesis that gravity affects the ability of biological systems to repair and recover from radiation damage. Scientists will observe radiation-damaged Bacillus subtilis bacteria to see if they form microcolonies to begin their repair process.

Science: Scientists for this experiment have selected a variety of bacteria cultures that are genetically well-defined, each having a different capacity to repair damage to its deoxyribonucleic acid (DNA). The first step in the repair process is for cell proteins to recognize damaged sites in the DNA. This involves the initial random collision of molecules and may be affected by gravity.

Significance: Scientists will use data from this experiment to understand more about the ability of biological systems to repair themselves after radiation damage in space. Before humans can stay in space on longer

Space Shuttle flights or live and work for extended periods of time aboard the space station, we must know more about the role that microgravity plays in the ability of cells to repair themselves after being exposed to radiation on orbit.

Operations: Three containers with X-ray irradiated bacteria spores and a pipette with a culture medium syringe are launched in Spacelab. During the last days of IML-2, bacteria cultures will be activated and placed into the Biorack 99 degrees Fahrenheit (37-degree Celsius) incubator. After about 20 hours of incubation, photographs will be taken of the microcolonies using the Biorack glovebox camera. Scientists on the ground will watch downlink television to determine when the cells should be preserved. The kinetics and efficiency of these bacteria cells in repairing DNA will be analyzed after the mission.

Background: This is a new investigation that has not flown before.

Radiation Repair Kinetics in Eukaryotes (Kinetics)

Experiment Facility: Biorack
Principal Investigator:
Dr. Gerda Horneck
DLR Institute for Aerospace Medicine
Cologne, Germany

Objective: This experiment will examine the ability of radiation-damaged cells to repair themselves in microgravity.

Science: Scientists will use human skin fibroblast and bacterial cells, Escherichia coli and Deinococcus radiodurans, to understand more about how cells repair themselves in space. Although scientists are aware that microgravity and radiation exposure affect living organisms, the ability of cells to repair and recover has not been explored in microgravity.

Significance: The Spacelab module has special radiation shielding, but some cosmic radiation does penetrate the spacecraft. Previous investigations indicate that radiation can be particularly damaging to single cells and that cells exposed to both microgravity and radiation may suffer more damage than cells exposed to only one of these effects. Before humans can stay in space for extended periods of time, we must first understand how cells repair themselves when they have been exposed to microgravity and radiation.

Operation: For this experiment, the cells will be exposed to ionizing radiation before the mission to damage their deoxyribonucleic acid (DNA), causing effects such as strand breakage in the double helix. The cells will be frozen until this experiment begins to prevent them from starting the healing process before they are exposed to microgravity on orbit. A commercial thermos has been modified to keep samples frozen during launch. Immediately after Spacelab activation, the vessels containing the cell samples will be transferred to the refrigerator/freezer where they will remain until they are activated during the mission. After activation, the cell samples will be incubated at 37 degrees Celsius (99 degrees Fahrenheit) for defined periods of time to allow the cells' enzyme systems to repair the damage from the ionizing radiation. After the various incubation periods, these samples will be returned to the refrigerator/freezer for their flight back to Earth. Freezing the cells in different stages of repair will allow scientists to see how much radiation damage was left unrepaired in microgravity. After the mission, investigators will examine the DNA and compare the cells that repaired themselves in microgravity with samples that repaired themselves on Earth.

Background: This is a new Biorack experiment that has not been flown before.

Real-Time Radiation Monitoring Device (RRMD)

Payload Developer: NASDA
Principal Investigator:
Dr. Tadayoshi Doke
Waseda University
Tokyo, Japan

Objective: This device will actively measure the high- energy cosmic radiation which enters the Spacelab in orbit, then transmit those measurements to the science team at the Payload Operations Control Center in Huntsville. The signals also will be transmitted to remote centers where they will be compared with other current radiation information, such as optical and X-ray observations.

In addition to real-time radiation monitoring, the device will contain bacteria with high radiation sensitivity. Scientists will analyze the bacteria cells post flight to measure radiation damage and study their ability to recover and repair themselves after a cosmic-ray impact.

Significance: This IML-2 device is the first to transmit radiation information to the ground during a mission. It serves as the beginning toward creation of a space weather- forecasting network which might be established for future spacecraft.

Space is a complex environment filled with electromagnetic radiation and charged particles. Previous experiments have shown that particles of high-energy radiation have potentially serious biological effects on living organisms. Earth's atmosphere shields people on the ground from most of these effects, but space travelers do not have the atmosphere to protect them. On longer spaceflights, radiation storms due to increased levels of solar activity could be hazardous to astronauts. A reliable space radiation forecasting system could warn them to take shelter in a protected area of their spacecraft until the danger has passed.

Experiment Hardware and Operations: The Real-time Radiation Monitoring Device consists of a detector unit, a control unit, and passive track dosimeters. The detector 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 the Spacelab, a spectroscope sensor measures the energy and direction of the particle. The electronic control unit records signals from the detector and transmits them to the ground. Also, the radiation-sensitive bacteria are sandwiched between solid-state nuclear track detectors in a container on top of the spectrometer.

The crew will mount the monitoring device in the Spacelab aft end cone shortly after launch. It will collect data throughout the mission. Crew members will change the direction the device faces about once every three days.

After the mission, records of real-time radiation readings will be compared to information from the passive radiation trackers, attached with biological specimens on top of the active detectors. They also will be compared with Biostack detector data from this and previous missions.

Background: IML-2 is the first flight of this experiment. It was developed by the National Space Development Agency of Japan as an addition to their life science hardware from Spacelab-J.

Microgravity Effects on Standardized Cognitive Performance Measures

Principal Investigator:
Dr. Samuel G. Schiflett
U. S. Air Force Armstrong Laboratory
San Antonio, Texas

Objective: This experiment will help determine astronauts' mental ability to perform operational tasks in space. Scientists want to measure how well the crew processes information so they can distinguish between the effects of microgravity and fatigue.

Six computerized cognitive performance tests called the Performance Assessment Workstation (PAWS) will be used during the flight. After Columbia lands, Air Force personnel, standing in for the STS-65 crew, will re-enact all mission procedures. The scientists will compare the results of the two groups in an effort to precisely pinpoint the effects of microgravity.

Significance: 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. The Performance Assessment Workstation provides scientists with a tool to assess cognitive performance and, thus, measure the impact of new and unknown stress factors.

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 results will provide information to help planners more effectively schedule astronauts' work under a variety of conditions, such as fatigue. This should lead to improved productivity during space missions through, for example, scheduling tasks at times when crew members' performance is optimum.

Science: Present day space travelers are subject to a variety of stresses during space flight. These include the microgravity environment, physical isolation, confinement, lack of privacy, fatigue and changing work-rest cycles. On Earth, both fatigue and changing work-rest cycles are known to degrade cognitive performance and productivity.

Hardware: The crew will undergo performance tests using a laptop computer. The Performance Assessment Workstation tests are based on current theoretical models of human performance. They were selected by analyzing tasks involved in space missions that might be sensitive to microgravity. Subjective questions also are included in PAWS for interpreting fatigue and mood states.

The investigation uses a set of six computerized cognitive performance tests taken from the Unified Tri-Service Cognitive Performance Assessment Battery. The series of tests is internationally recognized and has proven sensitive to many environmental stressors.

Operations: While in orbit, crew members will take the tests daily. The computer will record 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. The computer screen will be divided in half to feature two test questions. Each screen will be answered in a sequential manner determined by an indicator at the bottom of the screen. For example, the left screen might illustrate a spatial ability test while the right screen features an addition test.

Performance criteria for comparison will be collected during practice sessions held during the weeks before launch for the crew member subjects. Also, scientists will continue to gather data after the astronauts return to Earth. The postflight data will be collected to determine the rate of recovery of any detrimental effects of microgravity on cognitive information processing.

Spinal Changes in Microgravity

Payload Developer: Canadian Space Agency
Principal Investigator:
Dr. John R. Ledsome
Canadian Space Agency
Ottawa, Ontario, Canada

Objective: Two out of every three people who go into space experience back pain that scientists believe may be related to a lengthening of the spinal column in microgravity.

The objective of this IML-2 experiment is to determine whether the lengthening of the spinal column can be associated with changes in the function of the spinal cord or spinal nerve roots which branch off the spinal cord. It will investigate the effects of nerves that are stretched close to their limits by the lengthened spinal column, as well as the changes in body function controlled by the central nervous system.

In addition, the study will determine for the first time if the lengthening of the spinal column causes changes in the cardiovascular and bladder functions.

Science: The back does more than allow us to stand up straight. It houses the spinal cord and nerves that connect the spinal cord to the other parts of the body. It's likely that when the nerves are stretched they will not work properly. This experiment will study two types of these nerves: sensory nerves that carry signals from the skin to the brain and autonomic nerves that are responsible for involuntary bodily functions such as blood flow.

To determine the function of the sensory nerves, the ability of the spinal cord to conduct an electrical impulse from the foot to the brain will be measured. Normally when we breathe in, our heart rate decreases. When the breath is released, the heart rate increases. If there is a change in the interaction between breathing and heart rate, it might be due to changes to the autonomic nerves going to the heart.

The spacing between discs in the vertebrae will be measured to determine if that is the reason for the height increase, or if it is due to the straightening of the back's curvature.

Significance: This experiment will provide an insight into the function of the major nerves of the spinal cord during space flight and help understand the back pain reported by astronauts. The information has already proved valuable in understanding and assessing chronic back pain on Earth. Some of the techniques have been applied to back surgery performed in Canada.

Background: On IML-1, the first systematic measurements of changes in height and spinal contour were performed. Results indicated that the astronauts increased in height from two to three inches. There also was flattening of the normal spinal contour. Scientists believe this may be the cause of the back pain that many astronauts experience during space flight.

Operations: The STS-65 crew will complete a daily questionnaire describing any back pain and associated symptoms of spinal cord dysfunction, such as numbness. Crew members also will measure their height daily.

Three times during the flight -- at the beginning, middle and end -- they will take stereophotographs in seven different positions designed to provide information about changes in spinal contour, height and the

range of motion of the vertebral column. They also will be conducted pre- and post flight, along with magnetic resonance imaging of the spine and clinical back examination.

To study sensory nerves, crew members will stimulate their nerves with a tiny electric impulse at the ankle and time how long it takes the signal to reach the brain using a nerve stimulation and recording device. On Earth, it usually takes about 50-thousandths of a second, whereas in space the transit time is unknown.

To study autonomic nerves, crew members will squeeze a hand grip measuring device for several minutes -- a form of isometric exercise. At the same time, blood pressure and heart rate are measured to determine the adaptation of the heart to muscular work. A second study will measure heart rate as the astronaut synchronizes breathing to cues on an audiotape. Changes in the breathing/heart rate relationships are sensitive indicators of cardiac changes.

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

Payload Developer: NASDA

Objective: The Thermoelectric Incubator is a general- purpose incubator used in the Spacelab module to maintain biological specimens at a constant temperature, humidity and carbon-dioxide concentration. It provides a growth environment for both animal and plant cells.

The Cell Culture Kits will be used to culture slime mold and plant and animal cells in microgravity. The kits allow observation of cell growth, the extraction of materials produced by these cells, and the fixation of the cells for inspection after return to Earth.

The incubator and cell culture kits also will be used in conjunction with some of the Free Flow Electrophoresis Unit experiments.

Significance: This equipment allows scientists in the microgravity environment of Spacelab to study cell development and growth in much the same way as they would in their labs on Earth. Results will provide insight into how microgravity and radiation affect the development of cells in space. Comparison with ground-based experiments will help scientists understand how gravity shapes life on Earth.

Experiment Hardware and Operations: Cell-culture kits are pre-assembled packages of various items the scientist in orbit needs to perform culture experiments. They allow astronauts to take maximum advantage of the time available, as the kits make available in a single location all the equipment needed for a particular experiment.

Each kit includes a main chamber, containers for culture mediums, waste collectors, applicators, syringes and containment bags. For IML-2, three different types of kits will support animal cell-culture and electrophoresis experiments. Petri-dish-type chambers will be used for the slime mold and plant cells. Animal cell culture kits have transparent windows which allow crew members to observe cell cultures grown in orbit with a Biological Microscope. They will use a 35-mm camera, which attaches to the microscopes, to make still photographs of the samples.

For the slime mold culture, a video system will record and downlink real-time images of specimens to scientists at Spacelab Mission Operations Control in Huntsville. The Thermoelectric Incubator will operate at around 98.6 degrees Fahrenheit (37 degrees C). Experiment samples within the incubator are secured by a bungee cord to prevent damage from vibration and keep them from floating away when the door is opened.

Background: This equipment is provided by the National Space Development Agency of Japan. Along with the Free Flow Electrophoresis Unit and the Aquatic Animal Experiment Unit, it was part of the First Material Processing Test P Life Sciences, which flew aboard the Spacelab-J mission in 1992.

Gravity and the Stability of the Differentiated State of Plant Embryos

Experiment Facility: Cell Culture Kits
Principal Investigator:
Dr. Abraham Krikorian
State University of New York at Stony Brook
Stony Brook, New York

Objective: This experiment aims at determining the role gravity plays in the earliest stages of plant development. It will grow dally and carrot cells in two different culture environments to validate the outcome of its predecessor experiment on Spacelab-J. On that mission, a large number of plant cells developed with two nuclei. Cell division was taking place, but the walls which should have separated the two cells did not form.

Significance: This experiment will help determine if cell development can begin in the absence of gravity. It tests and profiles critical stages in plant cell development, called embryogenesis, and examines the effect of microgravity on cell division and chromosome behavior. The experiment also tests for other space environment effects such as radiation.

Results will provide fundamental biology information about the workings of a cell on Earth. Potential long-term benefits could range from manufacture of artificial seeds to the storage of vast, varied food supplies in a very small space (the size of a culture dish). This knowledge is critical for implementing space-based plant biotechnologies to feed future space travelers on long planetary flights.

Operations: Carrot and dally cells will be grown in six plant cell chambers and six plant fixation chambers, so that two basic types of cell culture environments can be evaluated.

Astronauts will place a radiation detector with the plant cell chambers and store them in a Spacelab rack compartment when the experiment begins. Cells with the ability to develop into embryos will be launched in a culture medium which keeps them inactive. Within a few days, the cells will be automatically developed themselves. These samples will be stored in the rack as well. Late in the flight, the crew will add a chemical to some of the cells to stop their growth and preserve their characteristics.

Comparison of the preserved samples with those returned to Earth alive will ensure that any abnormalities seen in the cells are not due to the stress of landing. Some of the space flight embryos will be incubated after the flight and examined on an ongoing basis for any temporary or longer-term effects of their genesis in the absence of gravity.

Background: On Dr. Krikorian's Spacelab-J experiment, both the degree and rate of development of plant cell generation were altered. There were significant abnormalities in the status and behavior of the nucleus of cells making up the embryo, with fracturing and changes in chromosome structure.

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

Experiment Facility: TEI
Principal Investigator:
Dr. Yasuhiro Kumei
Tokyo Medical and Dental University
Tokyo, Japan

Objective: This experiment compares functional differences in bone cell cultured in Earth's gravity compared to cells cultured in microgravity and determines the genes responsible for any differences. The ultimate goal is to clarify the causes for the bone atrophy, or osteoporosis, induced by space flight.

Significance: Previous Shuttle experiments have shown that animals lose calcium during space flight. Ninety percent of the calcium is found in the bone. Bone loss could pose more serious hazards for space travelers on long-duration missions. It's hypothesized that genes governing bone production are either stimulated or suppressed during space flight.

In addition to benefiting the health of future space crews, an increased understanding of the mechanism of osteoporosis eventually could help prevent bone disease on Earth and improve therapy for immobilized patients who experience similar bone atrophy.

Operations: Four culture chambers filled with bone cells from the back legs of young adult rodents will be studied in this experiment. Those cells are particularly sensitive to the sudden absence of gravity's pull on the skeleton in space. Astronauts will make microscopic and photographic observations of cell growth through transparent windows in the animal cell culture containers.

The cultures will grow in the Thermoelectric Incubator at 98.6 degrees Fahrenheit (37 degrees C), beginning just a few hours after launch. Three days later, crew members will remove two culture chambers from the incubator. They will extract cell samples from both chambers and refrigerate them. Other samples from those two containers will be frozen. The two remaining cell culture containers will continue to incubate until Flight Day 9, when the collection procedure will be repeated.

After the mission, the samples will be examined for the differences in bone cell production during exposure to microgravity.

Differentiation of *Dictyostelium discoideum* in Space

Experiment Facility: Cell Culture Kits
Principal Investigator:
Dr. Takeo Ohnishi
Nara Medical University
Nara, Japan

Objective: This experiment will provide information on how microgravity and radiation stress cells in space and affect their genetic development and shape. Two strains of slime mold cells (Dictyostelium discoideum), whose distinctive development has been studied extensively on Earth, will be grown in space to identify any differences.

Significance: Slime molds, found among decaying forest leaves and in topsoil, emerge from spores. During cell differentiation, (the process through which the molds attain their adult form) the spores show very distinct structural changes at various stages of cell division. Scientists are quite familiar with these structural stages on Earth, so comparisons with cells grown in orbit should provide extensive insight into how cell development and differentiation are affected by the space environment.

Operations: This experiment will grow a radiation- sensitive strain of slime mold and a wild-type strain which should be capable of DNA repair against radiation damage. Comparison of the two strains' development will help distinguish between the effects of microgravity and those of cosmic rays.

The organisms will be grown in plant cell culture chambers. Shortly after the IML-2 payload is activated, a crew member will remove the slime mold cell culture kit from its middeck locker. After attaching a radiation detector to the kit, the astronaut will place it in the middeck refrigerator/incubator.

On Flight Day 2, an astronaut will remove the slime mold kit from the refrigerator, incubate it for an hour in the Biorack incubator, then activate growth by injecting a buffer solution into the culture. The kit will be put back in the Biorack incubator, where it will remain for 4-1/2 days at 72 degrees Fahrenheit (22 degrees C). A video camera attached to the culture chamber will observe and record changes in cell shapes during growth. As they are taken, the images will be downlinked to experiment controllers on the ground.

After the flight, scientists will evaluate the health of the spores grown in space. Radiation effects will be determined by comparing the two types of slime mold.

ORBITAL ACCELERATION RESEARCH EXPERIMENT (OARE)

Payload Developer: NASA
Project Manager:
Mr. Jose L. Christian Jr.
NASA Lewis Research Center
Cleveland, Ohio

Objective: 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 atmosphere (near vacuum), and is slightly slowed (decelerated) by friction with it. Because the density of the atmosphere changes from day to night, the amount of friction (decelerating force) varies proportionally.

The Orbital Acceleration Research Experiment (OARE) makes extremely accurate measurements of these variations and other disturbances with a sensor called an accelerometer and records them for later analysis. By analyzing these and other types of microgravity disturbances, researchers can assess the influence of Shuttle accelerations on scientific experiments carried onboard.

Significance: The OARE is an instrument that monitors and records extremely small accelerations (changes in velocity) and vibrations experienced during Space Shuttle on-orbit operations. 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: to provide scientists with important information regarding aerodynamic drag (friction with the atmosphere) and upper atmosphere density (thickness of the air at high altitudes) that is impossible to obtain on Earth, and to study the high velocity, low density flight environment known as rarefied flow aerodynamics. This basic research 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 Miniature Electrostatic Accelerometer (MESA). The MESA has a cylindrical mass (called a proof mass) suspended within the accelerometer housing. The proof mass is pulled in different directions by static electric fields applied to 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.

The accelerometer mounts on a movable table that allows accurate alignment with respect to the Shuttle's flight direction. In-flight calibration is also made possible by the movable mounting system. 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.

The instrument is provided by NASA's Lewis Research Center in Cleveland, Ohio.

COMMERCIAL PROTEIN CRYSTAL GROWTH

This payload is sponsored by the Office of Advanced Concepts and Technology (OACT) as part of the commercial development of space programs within the OACT Space Processing Division. The payload and payload management are with the Center for Macromolecular Crystallography located at the University of Alabama at Birmingham, a NASA Center for the Commercial Development of Space.

This is the fifth flight (CPCG-05) of the protein crystal growth secondary payloads using the Commercial Refrigerator/Incubator Module (CRIM) in the Shuttle middeck. This complement of experiments contains 60 different samples focusing on six proteins in various formulations to enhance the probabilities for successful results. The crystals will be grown using the CMC Vapor Diffusion Apparatus (VDA) which allows proteins to be processed at a temperature of four degrees C rather than the normal 22 degrees C. The lower temperature requires a longer processing time which will be satisfied by the STS-65 14-day mission duration.

Commercial partners on this experiment with the UA-B CMC are SmithKline Beecham Pharmaceuticals and Vertex Pharmaceuticals. The firms and the university are researching the development of drugs which could provide some benefit to victims of AIDS, osteoporosis and toxic shock syndrome as well as providing a better understanding of the regulation of the human immune system and antibiotic resistance.

Dr. Larry DeLucas is the Director of the Center for Macromolecular Crystallography. The UA-B protein crystal growth apparatus first flew on STS-26 in September 1988, and in various improved versions, has flown 16 previous missions, the most recent of which was STS-62 in March.

AIR FORCE MAUI OPTICAL SYSTEM

The Air Force Maui Optical System (AMOS) is an electrical-optical facility on the Hawaiian Island of Maui. No hardware is required aboard Columbia to support the experimental observations. The AMOS facility tracks the orbiter as it flies over the area and records signatures from thruster firings, water dumps or the phenomena of “Shuttle glow,” a well-documented fluorescent effect created as the Shuttle interacts with atomic oxygen in Earth orbit. The information obtained by AMOS is used to calibrate the infrared and optical sensors at the facility. AMOS is a Department of Defense payload and is flown under the direction of the DOD Space Test Program.

MILITARY APPLICATIONS OF SHIP TRACKS

The Office of Naval Research (ONR) is sponsoring the Military Applications of Ship Tracks (MAST) experiment on STS- 65. MAST is part of a five-year research program developed by ONR to examine the effects of ships on the marine environment. The Naval Postgraduate School, Monterey, Calif., will conduct the experiment at JSC during the mission. The objective of MAST is to determine how pollutants generated by ships modify the reflective properties of clouds. Ship tracks are observed in satellite imagery as long, narrow, curvilinear cloud features that have greater brightness than the surrounding clouds. The STS-65 crew will photograph ship tracks using handheld cameras. These high-resolution photographs will provide insight into the processes of ship track production on a global scale. MAST will help in understanding the effects of man-made aerosols on clouds and the resulting impact on the climate system. MAST is a Department of Defense payload and is being flown under the direction of the DOD Space Test Program.

SHUTTLE AMATEUR RADIO EXPERIMENT (SAREX)

Students in the U.S., Germany and Japan will have a chance to speak, via amateur radio, with astronauts aboard the Space Shuttle Columbia during STS-65. Ground-based amateur radio operators ("hams") will be able to contact the Shuttle through automated computer-to-computer amateur (packet) radio links. There also will be voice contacts with the general ham community as time permits.

Shuttle mission specialists Donald A. Thomas (call sign KC5FVF) and Robert D. Cabana (license pending) will talk with students in 13 schools in the U.S., Germany and Japan using "ham radio."

Students in the following schools will have the opportunity to talk directly with orbiting astronauts for approximately 4 to 8 minutes:

- Sacred Hearts Academy, Honolulu, HI (WH6CJU)
- Kline School, Costa Mesa, Calif. (WB6NUD)
- Mountain View School, Phoenix, AZ (WB7VVD)
- Granite Mountain Middle School, Prescott, AZ (KB7TRE)
- West Monroe High School, West Monroe, LA (N5MYH)
- Our Lady Queen of Heaven, Lake Charles, LA (N5JDB)
- Richland Elementary, Ft. Worth, TX (KB5CXR)
- West-Oak High School, Westminster, SC (KR5GZ)
- Brentwood School, Sanderville, GA (AD4ID)
- Bair Middle School, Sunrise, FL (W4ROA)
- South Seminole Middle School, Casselberry, FL (KD4SRD)
- Fronhofer-Realschule Ingolstadt, Bavaria, Germany (DG4MKR)
- Tatebayashi Children's Science Exploratorium, Gunma, Japan (JQ1GOE)

The radio contacts are part of the SAREX (Shuttle Amateur Radio EXperiment) project, a joint effort by NASA, the American Radio Relay League (ARRL), and the Radio Amateur Satellite Corporation (AMSAT).

The project, which has flown on 13 previous Shuttle missions, is designed to encourage public participation in the space program and support the conduct of educational initiatives through a program to demonstrate the effectiveness of communications between the Shuttle and low-cost ground stations using amateur radio voice and digital techniques.

Information about orbital elements, contact times, frequencies and crew operating schedules will be available during the mission from NASA, ARRL (Steve Mansfield, 203/666- 1541) and AMSAT (Frank Bauer, 301/ 286-8496). AMSAT will provide information bulletins for interested parties on INTERNET and amateur packet radio. The ARRL bulletin board system (BBS) number is (203) 688-0578.

The ARRL ham radio station (W1AW) will include SAREX information in its regular voice and teletype bulletins.

Mission information will be available on-line from the Johnson Space Center computer bulletin board (8 N 1 1200 baud): dial (713) 244-5625. BBS information is available from the Goddard Space Flight Center amateur radio club via Internet. The address is: wa3nan@gsfc.nasa.gov.

The amateur radio station at the Goddard Space Flight Center, (WA3NAN), will operate around the clock during the mission, providing SAREX information, retransmitting live Shuttle air-to-ground audio, and retransmitting many SAREX school group contacts.

STS-65 SAREX Frequencies

Routine SAREX transmissions from the Space Shuttle may be monitored on a worldwide downlink frequency of 145.55 MHz.

The voice uplink frequencies are (except Europe):

144.91 MHz
144.93
144.95
144.97
144.99

The voice uplink frequencies for Europe only are:

144.70
144.75
144.80

Note: The astronauts will not favor any one of the above frequencies. Therefore, the ability to talk with an astronaut depends on selecting one of the above frequencies chosen by the astronaut.

The worldwide amateur packet frequencies are:

Packet downlink	145.55 MHz
Packet uplink	144.49 MHz

The Goddard Space Flight Center amateur radio club planned HF operating frequencies:

3.860	7.185	14.290	21.390	28.650
MHz				

STS-65 CREWMEMBERS

STS065-S-002 -- STS-65 Columbia, Orbiter Vehicle (OV) 102, International Microgravity Laboratory 2 (IML-2) official crew portrait shows its seven crewmembers wearing launch and entry suits (LESs). The six NASA astronauts and a Japanese payload specialist take a break from STS-65 training to pose for their portrait. Left to right are mission specialist and payload commander Richard J. Hieb, holding mission insignia, mission specialist Leroy Chiao, pilot James D. Halsell Jr., mission commander Robert D. Cabana, payload specialist Chiaki Mukai, mission specialists Donald A. Thomas, holding launch and entry helmet (LEH), and Carl E. Walz. Mukai represents the National Space Development Agency (NASDA) of Japan. Portrait made by NASA JSC contract photographer Scott A. Wickes.

BIOGRAPHICAL DATA

ROBERT D. CABANA, 45, Col., USMC, will be Commander (CDR) of STS-65. Selected as an astronaut in 1985, Cabana was born in Minneapolis, Minn., and will be making his third space flight.

Cabana graduated from Washburn High School, Minneapolis, in 1967 and received a bachelor's degree in mathematics from the Naval Academy in 1971.

Cabana completed naval flight officer training in 1972 and then served as an A-6 bombardier/navigator with Marine Air Wings, Cherry Point, N.C., and Iwakuni, Japan, until 1975. He then completed pilot training and was designated a naval aviator in 1976, and assigned to Cherry Point where he flew A-6 Intruders. In 1981, he graduated from the Naval Test Pilot School and later served at the Naval Air Test Center as the A-6 program manager, X-29 advanced technology demonstrator project officer, and as a test pilot for flight systems and ordnance separation testing on the A-6 and A-4 aircraft. At the time of his selection by NASA, he was serving as the assistant operations officer of Marine Aircraft Group Twelve in Iwakuni.

Cabana's first Shuttle flight was as pilot of STS-41 in October 1990, a mission that deployed the Ulysses planetary probe to study the polar regions of the Sun. He next flew as pilot of STS-53 in December 1992, a mission that deployed the classified Department of Defense-1 payload.

Cabana has logged more than 273 hours in space and more than 4,700 flying hours in 32 different types of aircraft.

JAMES DONALD HALSELL Jr., 37, Lt. Col., USAF, will serve as Pilot of STS-65.

Selected as an astronaut in 1990, Halsell was born in Monroe, La., and will be making his first space flight.

Halsell graduated from West Monroe High School in 1974; received a bachelor's degree in engineering from the Air Force Academy in 1978; received a master's degree in management from Troy University in 1983; and received a master's degree in space operations from the Air Force Institute of Technology in 1985.

Halsell completed undergraduate pilot training at Columbus Air Force Base, Mississippi, in 1979 and was assigned to Nellis Air Force Base, Las Vegas, Nev., as an F-4D aircraft commander. In 1981, he was stationed at Moody Air Force Base, Valdosta, Ga., serving as squadron flight lead, instructor pilot, strike package commander and chief of the Squadron Standardization/Evaluation Branch. Later, as a student at the Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Oh., his master's thesis prototyped a space rescue transfer vehicle using off-the-shelf equipment and was sponsored by the Johnson Space Center's (JSC) Crew Systems Division. Halsell then attended the Air Force Test Pilot School at Edwards Air Force Base, Calif., serving as a test pilot in the F-4, F-16 and the SR-71 aircraft in the years following his graduation.

RICHARD J. HIEB, 38, will be Payload Commander and Mission Specialist 1 (MS1). Selected as an astronaut in 1985, Hieb was born in Jamestown, N.D., and will be making his third space flight.

Hieb graduated from Jamestown High School in 1973; received a bachelor's degree in math and physics from Northwest Nazarene College in 1977; and received a master's degree in aerospace engineering from the University of Colorado in 1979.

Hieb joined NASA in 1979, working at JSC in crew procedures development and crew activity planning. He worked on the ascent team in Mission Control for STS-1 and during rendezvous phases of many subsequent missions, specializing in rendezvous and proximity operations.

He first flew as a Mission Specialist on STS-39 in May 1991, a Department of Defense mission that deployed and later retrieved the Infrared Background Signature Survey satellite. His next flight was as a Mission Specialist on STS- 49 in May 1992, a mission that retrieved and repaired the stranded Intelsat VI F3 communications satellite. During that flight, Hieb performed three space walks totaling more than 17 hours for the capture and repair of the satellite.

Hieb has logged more than 400 hours in space.

BIOGRAPHICAL DATA

CARL E. WALZ, 38, Lt. Col., USAF, will be Mission Specialist 2 (MS2). selected as an astronaut in 1990, Walz was born in Cleveland, Oh., and will be making his second space flight.

Walz graduated from Charles F. Brush High School, Lyndhurst, Oh., in 1973; received a bachelor's degree in physics from Kent State University in 1977; and received a master's degree in solid state physics from John Carroll University in 1979.

Walz was commissioned in the Air Force following graduation from Kent State, and after completing graduate studies at John Carroll, he was assigned to the 1155th Technical Operations Squadron at McClellan Air Force Base, Calif. In 1983, he attended the Air Force Test Pilot School at Edwards Air Force Base, Calif., as a flight test engineer, and he was assigned to the F-16 Combined Test Force at Edwards following graduation.

Walz' first Shuttle flight was as a Mission Specialist on STS-51 in September 1993, a mission that deployed the Advanced Communications Technology Satellite. Walz has logged more than 236 hours in space.

LEROY CHIAO, Ph.D., 33, will be Mission Specialist 3 (MS3). Selected as an astronaut in 1990, Chiao considers Danville, Calif., his hometown and will be making his first space flight. Chiao graduated from Monte Vista High School in Danville in 1978; received a bachelor's degree in chemical engineering from the University of California, Berkeley, in 1983; and received a master's degree and a doctorate in chemical engineering from the University of California, Santa Barbara, in 1985 and 1987, respectively.

In 1987, Chiao joined the Hexcel Corporation in Dublin, Calif., working in process, manufacturing and engineering research on advanced aerospace materials. Chiao joined the Lawrence Livermore National Laboratory in 1989 and performed processing research on filament-wound and thick- section aerospace composites. Chiao developed and demonstrated a mechanistic cure model for graphite fiber/epoxy composite material.

Chiao's technical assignments as an astronaut have included Shuttle flight software verification and work with crew equipment design issues.

DONALD A. THOMAS, Ph.D., 39, will be Mission Specialist 4 (MS4). Selected as an astronaut in 1990, Thomas was born in Cleveland, Oh., and will be making his first space flight.

Thomas graduated from Cleveland Heights High School in 1973; received a bachelor's degree in physics from Case Western Reserve University in 1977; and received a master's degree and a doctorate in materials science from Cornell University in 1980 and 1982, respectively.

Thomas joined AT&T Bell Laboratories in 1982 as a senior member of the technical staff, working on high density interconnections of semiconductor devices. He also served as an adjunct professor in the Trenton State College Physics Department.

In 1987, he joined Lockheed Engineering and Sciences Company in Houston where his work involved reviewing materials for Shuttle payloads. He joined NASA in 1988 as a materials engineer at JSC, performing work that involved lifetime projections of advanced composite materials for use on space station. He also was a principal investigator for the Microgravity Disturbances Experiment, a crystal growth experiment which flew on STS-32 in January 1990.

Thomas' technical assignments in the Astronaut Office have included working as a spacecraft communicator in Mission Control and as a representative to the safety and operations development branches.

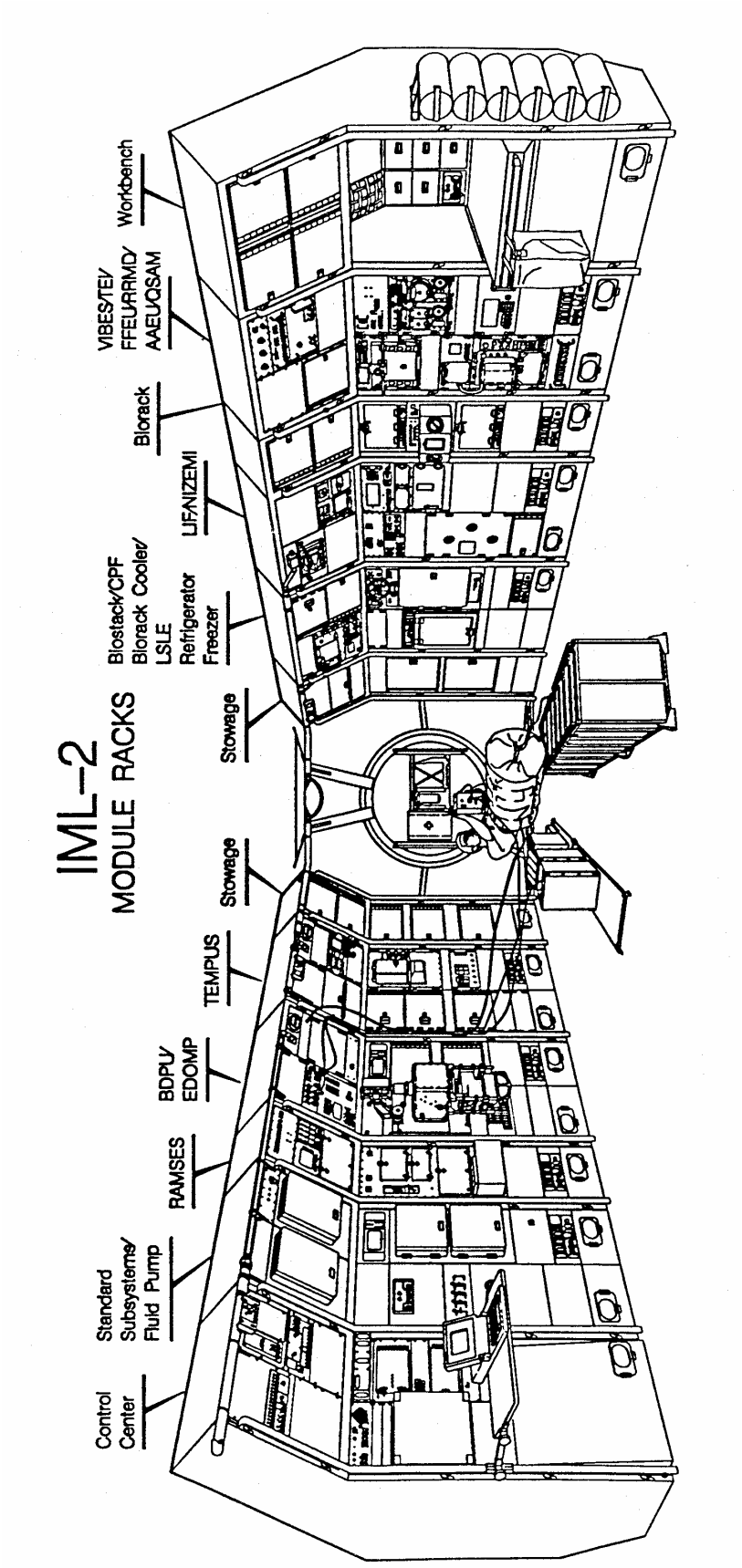
BIOGRAPHICAL DATA

CHIAKI NAITO-MUKAI, MD, Ph.D., 41, will be Payload Specialist 1 (PSI). Selected as a science astronaut by the National Space Development Agency of Japan (NASDA) in 1985, Mukai was born in Tatebayashi, Gumma Prefecture, Japan, and will be making her first space flight.

Mukai graduated from Keio Girls' High School, Tokyo, in 1971; received her doctor of medicine degree from Keio University School of Medicine in 1977; and received a doctorate in physiology from the Keio University School of Medicine in 1988. She was board certified as a cardiovascular surgeon by the Japan Surgical Society in 1989.

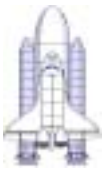
Mukai was board certified for Clinical Medicine in 1977, and, until 1979, worked as a resident in General Surgery at Keio University Hospital, Tokyo. In 1978, she was on the medical staff in Emergency Surgery at Saiseikai Kanagawa Hospital, Kangewa Prefecture. In 1980, she began work as a resident in cardiovascular surgery at Keio University Hospital and on the medical staff of cardiovascular surgery at Saisekai Utsunomiya Hospital, Tochigi Prefecture. In 1983, she returned to Keio University Hospital as the chief resident in cardiovascular surgery and later became the assistant professor of the Department of Cardiovascular Surgery.

Mukai was selected by NASDA in 1985 as one of three payload specialist candidates for the Japanese Spacelab, Spacelab-J, on Shuttle mission STS-47. She became a visiting scientist of the Division of Cardiovascular Physiology at the Space Biomedical Research Institute at JSC from 1987 to 1988. Mukai is credited with more than 50 publications since 1979.


IML-2
MODULE RACKS
Control Center
Standard Subsystems/ Fluid Pump
RAMSES
BDPU/ EDOMP
TEMPUS
Stowage
Stowage
Biostack/CPF
Biorack Cooler/ LSLE
Refrigerator Freezer
LIFANIZEMI
Biorack
VIBES/TEI/ FFEU/ARMD/ AAEU/QSAM
Workbench

SHUTTLE FLIGHTS AS OF JULY 1994

62 TOTAL FLIGHTS OF THE SHUTTLE SYSTEM -- 37 SINCE RETURN TO FLIGHT



OV-102 Columbia (16 flights)	OV-099 Challenger (10 flights)	OV-103 Discovery (18 flights)	OV-104 Atlantis (12 flights)	OV-105 Endeavour (6 flights)
STS-62 03/04/94 - 03/18/94		STS-60 02/03/94 - -2/11/94		
STS-58 10/18/93 - 11/01/93		STS-51 09/12/93 - 09/22/93		
STS-55 04/26/93 - 05/06/93		STS-56 04/08/83 - 04/17/93		
STS-52 10/22/92 - 11/01/92		STS-53 12/02/92 - 12/09/92		
STS-50 06/25/92 - 07/09/92		STS-42 01/22/92 - 01/30/92		
STS-40 06/05/91 - 06/14/91		STS-48 09/12/91 - 09/18/91		
STS-35 12/02/90 - 12/10/90	STS-51L 01/28/86	STS-39 04/28/91 - 05/06/91	STS-46 07/31/92 - 08/08/92	
STS-32 01/09/90 - 01/20/90	STS-61A 10/30/85 - 11/06/85	STS-41 10/06/90 - 10/10/90	STS-45 03/24/92 - 04/02/92	
STS-28 08/08/89 - 08/13/89	STS-51F 07/29/85 - 08/06/85	STS-31 04/24/90 - 04/29/90	STS-44 11/24/91 - 12/01/91	
STS-61C 01/12/86 - 01/18/86	STS-51B 04/29/85 - 05/06/85	STS-33 11/22/89 - 11/27/89	STS-43 08/02/91 - 08/11/91	
STS-9 11/28/83 - 12/08/83	STS-41G 10/05/84 - 10/13/84	STS-29 03/13/89 - 03/18/89	STS-37 04/05/91 - 04/11/91	
STS-5 11/11/82 - 11/16/82	STS-41C 04/06/84 - 04/13/84	STS-26 09/29/88 - 10/03/88	STS-38 11/15/90 - 11/20/90	
STS-4 06/27/82 - 07/04/82	STS-41B 02/03/84 - 02/11/84	STS-51-I 08/27/85 - 09/03/85	STS-36 02/28/90 - 03/04/90	STS-59 04/09/94 -04/20/94
STS-3 03/22/82 - 03/30/82	STS-8 08/30/83 - 09/05/83	STS-51G 06/17/85 - 06/24/85	STS-34 10/18/89 - 10/23/89	STS-61 12/02/93 - 12/13/93
STS-2 11/12/81 - 11/14/81	STS-7 06/18/83 - 06/24/83	STS-51D 04/12/85 - 04/19/85	STS-30 05/04/89 - 05/08/89	STS-57 06/21/93 - 07/01/93
STS-1 04/12/81 - 04/14/81	STS-6 04/04/83 - 04/09/83	STS-51C 01/24/85 - 01/27/85	STS-27 12/02/88 - 12/06/88	STS-54 01/13/93 - 01/19/93
		STS-51A 11/08/84 - 11/16/84	STS-61B 11/26/85 - 12/03/85	STS-47 09/12/92 - 09/20/92
		STS-41D 08/30/84 - 09/05/84	STS-51J 10/03/85 - 10/07/85	STS-49 05/07/92 - 05/16/92