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# A Decade of Life Sciences Experiment Unique Equipment Development for Spacelab and Space Station, 1990-1999

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## ABSTRACT

Ames Research Center's Life Sciences Division has developed and flown an extensive array of spaceflight experiment unique equipment (EUE) during the last decade of the twentieth century. Over this ten year span, the EUE developed at ARC supported a vital gravitational biology flight research program executed on several different platforms, including the Space Shuttle, Spacelab, and Space Station Mir. This paper highlights some of the key EUE elements developed at ARC and flown during the period 1990-1999. Resulting lessons learned will be presented that can be applied to the development of similar equipment for the International Space Station.

## INTRODUCTION

During the first two decades of the Space Shuttle program, the Life Sciences Division at Ames Research Center was busy developing the suite of animal and plant habitats that would be required to support non-human life sciences microgravity flight research on the Space Shuttle and in the Spacelab. These habitats were developed to support the basic research objectives of the gravitational biology research community. As specific principal investigators were selected to use these habitats as well as international partner-developed systems such as the European Space Agency (ESA) Biorack and Russian Svet greenhouse, it became clear that an additional suite of flight equipment would have to be developed on a mission-by-mission basis to satisfy investigation- specific requirements. In general, this experiment unique equipment (EUE) was required to:

- Meet a particular investigator's requirement for inflight collection of a specific tissue or sample and it's subsequent preservation or storage for postflight analysis.
- Measure and record specific physiological parameters inflight required by an investigator.
- Provide a medium for cells to develop inflight when using third party developed systems such as the ESA Biorack.

The process for developing EUE required the close collaboration of the principal investigator with a support team at Ames, which comprised science, engineering, operations, and safety/mission assurance personnel. EUE requirements were derived starting from the investigator's initial proposal and were further developed into an experiment requirements document (ERD), which became an agreement between the investigator and the Ames team. From the ERD, engineering specifications for the EUE were developed and preliminary and final designs were reviewed and agreed upon. Prototype EUE was developed and tested in concert with the design process, which allowed the investigator to verify that his/her specific requirements were being met in the EUE design. The investigator also worked closely with the Ames team to develop the flight procedures that would be followed by astronaut crewmembers when operating the EUE inflight. Finally, the investigator together with the Ames team developed ground procedures for the preflight preparation and postflight processing of EUE.

## OVERVIEW OF MAJOR LIFE SCIENCES DIVISION PAYLOADS

Beginning with the Spacelab-3 mission in May of 1985 and continuing through the Neurolab mission in April of 1998, the Life Sciences Division was an integral part of every major Spacelab mission flown. A brief summary of these missions follows:

- Spacelab-3 (May, 1985)- this mission featured the first flight of the Research Animal Holding Facility; its primary objective was hardware validation.
- Spacelab Life Sciences-1 (June, 1991)- this mission featured the second flight of the Research Animal Holding Facility and first flight of the General Purpose Work Station; its primary objective was hardware validation, and a secondary objective was the flight of a developmental biology microgravity experiment using jellyfish.
- International Microgravity Laboratory-1 (January 1992)- this mission featured the flight of the Gravitational Plant Physiology Facility and ESA Biorack; its primary objectives were plant and cell developmental biology microgravity research.
- Spacelab-J (September 1992)- this mission featured the first flight of the Frog Embryology Unit and the second flight of the General Purpose Work Station; its primary objective was amphibian developmental biology microgravity research.

- Spacelab Life Sciences-2 (October 1993)- this mission featured the third flight of the Research Animal Holding Facility and the General Purpose Work Station; its primary objectives were rodent hematology, vestibular, and musculoskeletal microgravity research.
- NASA/Mir Science Program (March 1995 to September 1997) - this program featured five collaborative long-duration research missions with the Russian Space Agency onboard the Mir space station and included the shared use of the Russian-developed "SVET" greenhouse and quail egg incubator. Circadian rhythm and radiation studies were also conducted onboard Mir.
- Neurolab (April 1998)- this final Spacelab mission featured the fourth flights of the Research Animal Holding Facility and General Purpose Work Station, the Animal Enclosure Module, and the collaborative use of the Japanese Vestibular Function Experiment Unit, and German CEBAS and BOTEX systems. The primary objective of the Neurolab mission was neurovestibular microgravity research.

## EXPERIMENT UNIQUE EQUIPMENT

Beginning with Spacelab Life Sciences-1, each of the Spacelab and Space Station missions described in the previous section required various EUE elements to satisfy flight research objectives not met by the basic habitat systems. Some of the key EUE elements developed in support of these missions are now highlighted.

SPACELAB LIFE SCIENCES-1 (SLS-1) - The SLS-1 experiment "The Effects of Microgravity- Induced Weightlessness on Aurelia Ephyra Differentiation and Statolith Syntheses" required a specialized system for holding jellyfish polyps in seawater and subsequently inducing metamorphosis through chemical catalysis. The system also had to provide a means for fixing some of the jellyfish for analysis postflight as well as providing a means for videotaping inflight swimming behavior of the remaining live specimens. Figure 1 is a picture of the jellyfish bags developed as EUE for the SLS-1 mission. Syringes containing thyroxine or iodine, gluteraldehyde, and a sodium cacodylate buffer solution were attached to the bag containing the jellyfish polyps in seawater. This assembly was in turn contained in two outer bags, which provided the necessary level of chemical containment while still allowing the crewmembers to manipulate the syringes inflight. This EUE was designed to meet the science objectives of principal investigator Dr. Dorothy Spangenburg of Eastern Virginia Medical School.

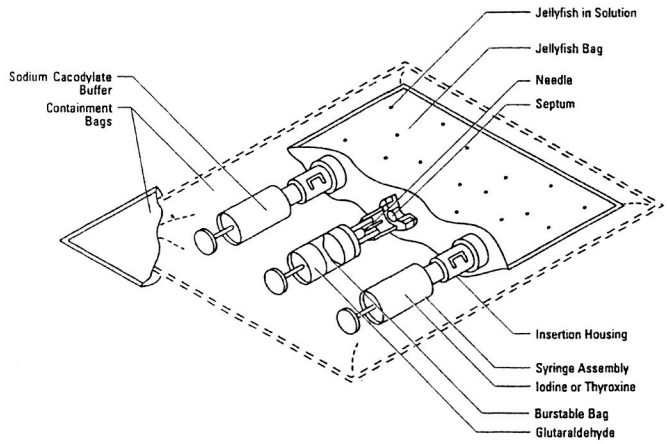


Figure 1 – SLS-1 Jellyfish Bag

INTERNATIONAL MICROGRAVITY LABORATORY-1 (IML-1) - ARC developed three different EUE elements for this mission. All three elements were developed for use with the ESA Biorack, an integrated flight research support system consisting of an incubator, centrifuge, and glovebox. The first EUE element developed for IML-1 was for the experiment "Genetic and Molecular Dosimetry of HZE Radiation" (PI, Dr. Greg Nelson, Jet Propulsion Laboratory). Shown in Figure 2 and identified as US-1, this hardware consisted of two basic components, each of which housed a microscopic soil nematode. The first component was a set of polycarbonate tubes containing a gel suspension and thin film nematode cultures, which was then loaded into ESA-provided type-I containers. The type-I containers were then placed in the Biorack centrifuge and/or incubator inflight. This allowed the measurement of gravity effects on growth and development of the nematodes. The second component of the US-1 EUE was a hollow metal block which was filled with a "sandwich" consisting of a stack of plastic neutron track detectors alternating with the nematode culture/gel suspension mixture. These blocks were placed in ESA-provided type II containers and mounted in various locations throughout Spacelab to sample the radiation environment under different levels of shielding.

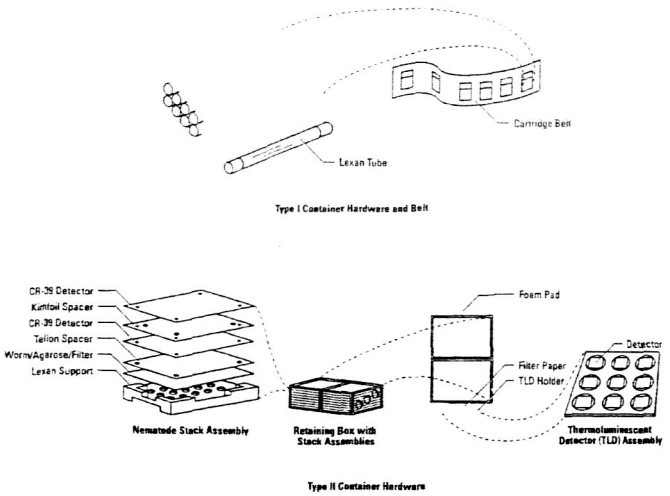


Figure 2 – IML-1/US-1 Experiment Unique Equipment

The second EUE element for the IML-1 mission was a type of cell culture chamber, developed for the experiment "Microgravitational Effects on Chromosome Behavior" (PI, Dr. Carlo Bruchi, Italy). Each double chamber had two culture wells consisting of a Lexan chamber fitted with a movable piston and a molecular layer of silicon to ease piston travel. The yeast plate had two grooved areas into which Lexan rings fit. Prior to fixation, the piston was pushed down to vent the air inside the chamber. Fixative was injected through the piston with a hypodermic syringe. This second EUE element is shown in Figure 3, and is identified as US-2. The yeast cells were fixed at various times and temperatures inflight.

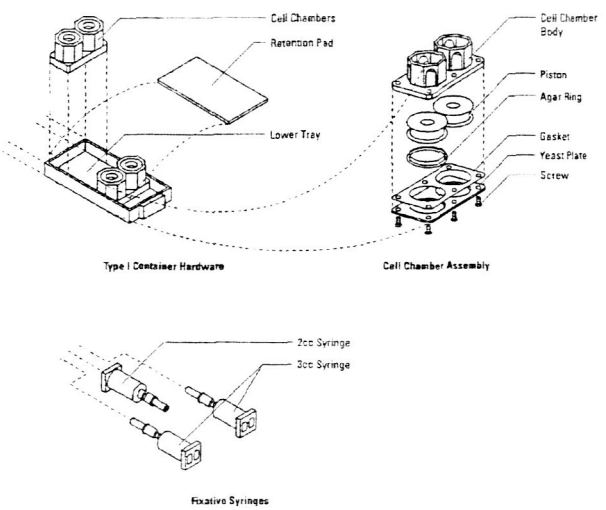


Figure 3 – IML-1/US-2 Experiment Unique Equipment

The third EUE element was a type of cell culture hardware supporting the experiment "Chondrogenesis in Micromass Cultures of Mouse Limb Mesenchyme Exposed to Microgravity" (PI, Dr. Jackie Duke, University of Texas Dental School). Figure 4 is a picture of this EUE, identified as US-3.

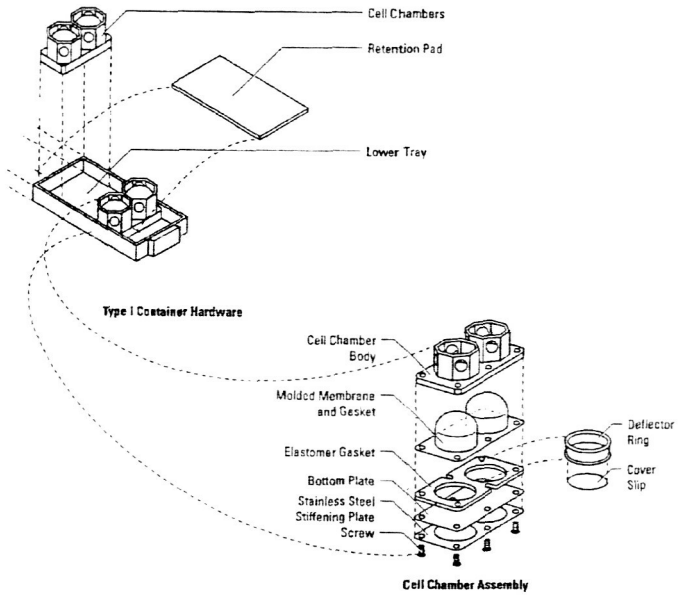


Figure 4 – IML-1/US-3 Experiment Unique Equipment

The US-3 cell culture chambers were Lexan polycarbonate with two wells. In each well was a bubble of a gas permeable material which expanded or collapsed as medium was added or removed. A silicon rubber gasket and bottom plate held cells cultured on coverslips. A deflector ring in the bottom of the chamber prevented fluid forces from dislodging or shearing the cells. Medium exchange and fixation was performed by inserting a hypodermic needle through the gasket and onto the cultures. The chambers were in turn housed in ESA-provided Type I aluminum containers for stowage in the Biorack incubator or centrifuge as required inflight.

SPACELAB-J (SL-J) - In support of the Frog Embryology Experiment (PI, Mr. Ken Souza, Ames Research Center) conducted during the SL-J mission, Ames developed several elements of EUE, including a dissecting microscope and frog egg chamber units (ECU's). The ECU's were lexan containers which allowed frog eggs removed from the female to be loaded into the chambers and fertilized inflight with sperm collected preflight from the male. The eggs in the ECUs could then be analyzed inflight with the dissecting microscope and video images recorded or downlinked during the mission. Figure 5 depicts the dissecting microscope and figure 6 depicts the ECU.

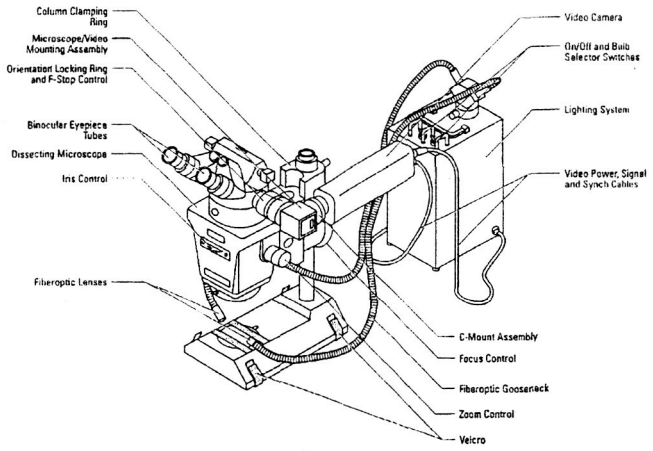


Figure 5 – SL-J Dissecting Microscope

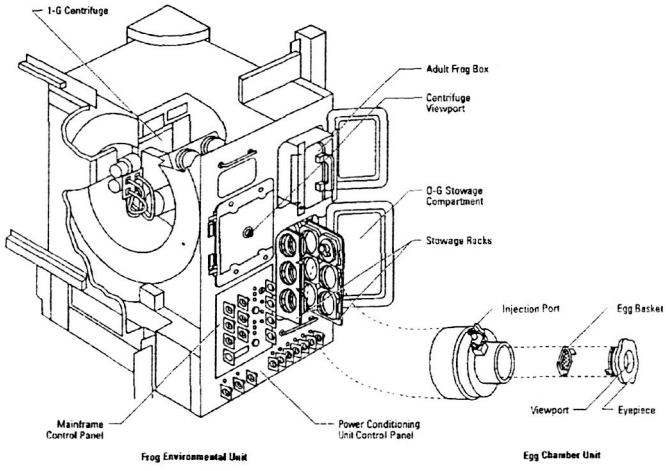


Figure 6 – SL-J Egg Chamber Unit

SPACELAB LIFE SCIENCES-2 (SLS-2) - Due to the extensive scope of inflight samples that were to be obtained during the SLS-2 mission, several different types of EUE were developed. The EUE developed in support of the rodent hematology experiments included blood collection and processing kits that were presented in a previous paper[1]. The vestibular and musculoskeletal experiments required the development of an inflight dissection kit. It consisted of an assembly of various surgical tools normally used in a laboratory, as well as standard laboratory animal decapitator modified for use in space. Finally, a unique configuration of the standard rodent RAHF waste tray was developed to allow for inflight collection of feces at various times during the mission as part of a metabolic calcium balance experiment. The SLS-2 EUE was developed to meet the science objectives of hematology PI's, Dr. Clarence Alfrey (Baylor College of Medicine) and Dr. Albert Ichiki (University of Tennessee Medical School), vestibular PI, Dr. Muriel Ross (Ames Research Center), and musculoskeletal PI's, Dr. Danny Riley (Medical College of Wisconsin), Dr. Ken Baldwin (University of California, Irvine), and Dr. Emily Holton (Ames Research Center).

NASA/Mir SCIENCE PROGRAM - Key elements of EUE were developed to support gravitational biology research onboard the Mir Space Station. This EUE included the development of a fixative kit, plant pollination kit, silique collection kit, and seed operations kit. These were developed to support the plant developmental biology experiment using the mustard plant Brassica rapa, in the Russian Svet greenhouse (PI, Dr. Mary Musgrave, Louisiana State University). Figures 7, 8, 9, and 10 depict the greenhouse EUE. A second EUE element developed for the Mir Space Station was a Beetle kit, used to study the circadian rhythms of a black-bodied beetle. This equipment has been presented in a previous paper [2]

Figure 7 – NASA/Mir Plant Fixative Kit

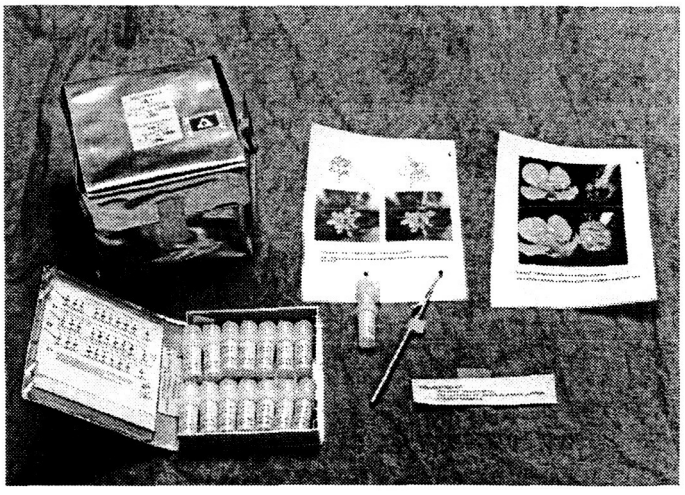

Figure 8 – Plant Pollination Kit

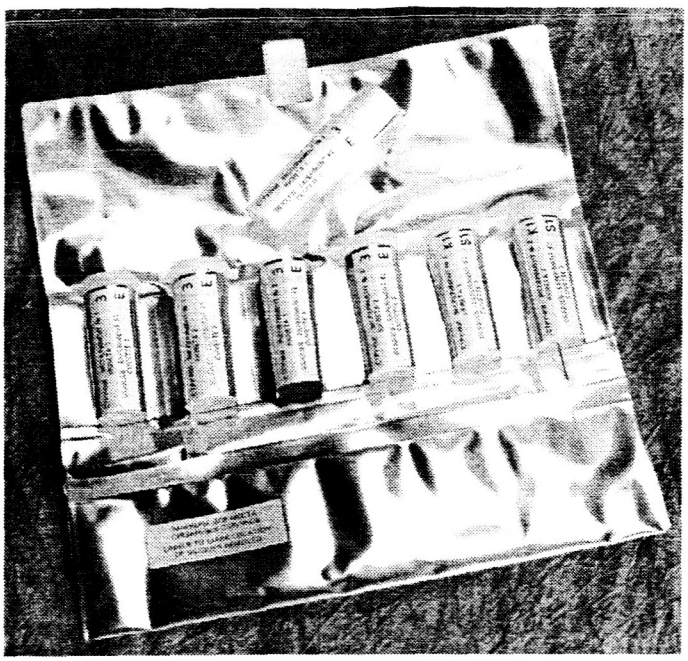

Figure 9 – Silique Collection Kit

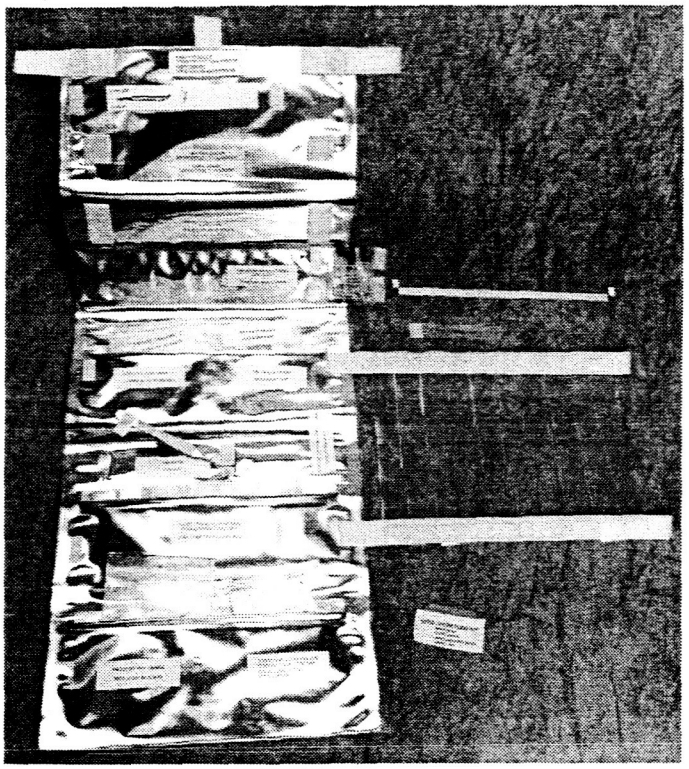

Figure 10 – Seed Operations Kit

NEUROLAB - The final flight of Spacelab, dedicated to neurovestibular microgravity resarch, also required perhaps the greatest level of sophistication yet in the scope of EUE developed to meet a particular investigator's science objectives. Two elements in particular are highlighted here.

The Neurolab mission included an experiment dedicated to the study of "Ensemble Coding of Place and Direction in Zero-G". The development of flight hardware for this experiment was the joint responsibility of the University of Arizona's Division of Neural Systems, Memory and Aging (NSMA) and NASA's Ames Research Center. The flight experiment, identified as E100, was conceived by Dr. Bruce McNaughton of NSMA, and explored how the central cortical and subcortical representation of spatial relationships is affected by microgravity. Specifically, ensemble neural activity in the parietal cortex, hippocampus, lateral dorsal thalamus, and superior colliculus was recorded in animals performing behavioral tasks using specialized behavioral apparatus. These apparatus, namely the "Escher Staircase" and the "Magic Carpet", were developed and flight qualified by ARC engineers and technicians. The Escher Staircase consisted of three L-shaped composite tracks, covered with closed cell foam and interconnected to form a closed circuit for an animal to navigate in space. The Magic Carpet, a cross-shaped track capable of rotation in two axes, allowed astronauts to test an animal's ability to maintain accurate position information in the absence of gravity. Experiment data were collected using a sophisticated NSMA biomedical implant that ARC reduced in size and manufactured to spaceflight standards. ARC also provided flight hardware packaging, environmental testing and system safety verification for the experiment's signal detection, processing and recording subsystems. These critical tasks significantly improved the reliability and robustness of the flight hardware. Two complete flight systems flew on Neurolab and allowed first-ever, state-of-the-art neuronal measurements to be made in space.

A second element of EUE developed was the Neurolab Biotelemetry System (NBS), supporting a flight experiment investigating central nervous system control of rhythm and homeostasis during spaceflight (experiment E150, Dr. Charles Fuller from UC-Davis, Principal Investigator). NBS monitored body temperature, heart rate and activity for 12 animals implanted with small radio-frequency transmitters. Custom software was designed for sampling, processing and storing flight data for a period of up to 21 days. NBS was developed using a combination of commercial and ARC developed hardware and custom software. The commercial hardware included implantable telemetry transmitters, receivers and flash memory. Ames provided system design and integration, packaging, signal conditioner design, receiving antenna development, custom software development, environmental testing and hardware safety verification for the NBS. The receiving antennas were custom-designed to fit within a rodent Research Animal Holding Facility (RAHF) cage and reliably detect near-field, radio-frequency signals from the implanted transmitters. During Neurolab, the NBS demonstrated its ability to detect and record wireless physiological measurements under non-ideal conditions without interfering with other Shuttle systems or experiments

## LESSONS LEARNED

Several characteristics of the EUE development

process will now be highlighted as critical links to the success or failure of the process. These lessons learned are an important legacy of the Spacelab and Mir Space Station research projects and should be considered during the EUE development process for the International Space Station.

REQUIREMENTS DEVELOPMENT - Early and accurate requirements definition and PI/project team agreement is critical since the selection of the principal investigator for flight typically occurs late in the development of a payload project. This requires a close and effective working relationship between the PI and the project team.

VALIDATION OF EXPERIMENT FEASIBILITY - An early assessment of the technical feasibility of accomplishing a particular investigator's science objectives is critical. This will ensure that any EUE required is within the scope of the capability and resources of the equipment developer.

DESIGN PROTOTYPING - Hand-in-hand with the design of the EUE, there must be an iterative design prototyping effort. This should be done with the investigator included as part of the design team, so that any issues associated with the design of the EUE can be identified through testing and evaluation of the prototype EUE, ideally at the investigator's facilities.

PROCEDURE DEVELOPMENT - The involvement of the investigator in the flight and ground operations procedure development is also critical. Again, working closely with the Project team the investigator can identify critical operational parameters associated with the preparation and use of the EUE.

TRAINING - The theme of investigator involvement continues when it comes to training flight crewmembers on the experiment operations to be performed inflight. As the operators of the flight experiment, the flight crew must have access to the investigator during the training process.

## CONCLUSION

The ten years of Shuttle/ Spacelab flight research experience and participation in the NASA/Mir Space Station research program have yielded a rich history of experiment unique equipment development experience and success which was a critical part to ensuring a full scientific return from each mission.

As the Life Sciences Division at Ames prepares to support the exciting new research afforded by the International Space Station in the 21st century, it does so with a solid foundation of experience gained during the last decade of the twentieth century.

## REFERENCES


1. "Development of Experiment Kits for Processing Biological Samples Inflight on SLS-2", 24th International Conference on Environmental Systems, Friedrichshafen, Germany, 1994.
2. "Development of Insect Habitat to Study Beetle Circadian Rhythms", 27th International Conference on Environmental Systems, Lake Tahoe, Nevada, 1997.