ABSTRACT

Bone mineral measurements before and after space missions have shown that weightlessness greatly accelerates bone demineralization. Bone mineral losses as high as 1 to 3% per month have been reported. Highly precise instrumentation is required to monitor this loss and thereby test the efficacy of treatment. During the last year, a significant improvement has been made in Dual-Photon Absorptiometry by replacing the radioactive source with an x-ray tube. Advantages of this system include: better precision, lower patient dose, better spatial resolution, and shorter scan times. The high precision and low radiation dose of this technique will allow detection of bone mineral changes of less than 1% with measurements conducted directly at the sites of interest. This will allow the required bone mineral studies to be completed in a shorter time and with greater confidence.

INTRODUCTION

It is well known that weight bearing bones demineralize if not subjected to mechanical stress. While the mechanism of this bone loss is not understood, it is clear that the reduced bone mineral density impairs the mechanical integrity of the skeletal system and may result in bone fractures. X-ray evidence of this demineralization is present at about 12 weeks in patients immobilized by major fractures or paralysis. Manned space flights have shown that extended periods of weightlessness have a similar effect. In US space flights lasting as long as 3 months, loss of bone mineral has not impaired the functional capabilities of astronauts. However, the prospect of extended and repeated flights requires additional bone mineral research to protect the health and insure the performance of space crews.

During the last year, a significant improvement has been made in Dual Photon Absorptiometry bone mineral measurement by replacing the radioactive source with an x-ray tube. Many factors motivate this change. The greater output flux of the x-ray tube permits shorter scan times and better precision. The smaller focal spot permits better beam collimation which results in better spatial resolution and lower patient dose. In addition, elimination of the radioactive material simplifies licensing and eliminates the need for yearly source replacement. These developments have been commercialized to monitor bone disorders in the general public. This paper discusses the operating principles of this new instrumentation and how it can be applied to manned space flight.

BONE DEMINERALIZATION

A gradual loss of bone mineral is normal throughout adulthood. It has been well established that bone mineral density decreases about 1% per year with variation depending on the site examined (Krolner and Pors Nielsen, 1982; Riggs et al, 1982). Many mechanisms are responsible for accelerated
bone loss beyond this natural ageing process. Bone demineralization is a
significant health problem for post menopausal women. In the United States,
osteoporosis affects some 15 to 20 million persons, and results in more than 1
million fractures annually. The lifetime risk of a hip fracture to a female in
the United States is about 15%, a similar risk as for breast cancer. Almost 20%
of these fracture patients die within six months, and it has been estimated that
40% of the survivors do not return to the independence of their pre-fracture
life-style.

While osteoporosis is a significant problem to the general public, it is an
even greater problem to manned space flight. Bone mineral measurements
before and after extended space missions have shown that weightlessness
greatly accelerates bone demineralization. Bone mineral losses as high as 1 to
3% per month have been measured (Anderson and Cohn, 1985). At this rate of
reduction, bone fractures could be expected in as little as 1-2 years. After
returning to a gravitational environment, this bone mineral loss is reversed
and at least some of the damage is repaired. Whether or not the bone mineral
is restored to a pre-space flight level is not clear. Measurements on the Skylab
astronauts five years after their flights were lower than before the flights and
lower than in controls (Tilton et al, 1980).

DUAL PHOTON ABSORPTIOMETRY

Drug, diet, and exercise therapies have been suggested to reduce bone loss.
A critical part of any therapy program will be the ability to make highly
precise bone mineral measurements. Precision, or the ability to make
repeatable measurements, is necessary to detect the small changes in bone
mineral that occur over a short period of time. In past experiments, the
imprecise measurements techniques have yielded error bars nearly as large as
the results trying to be measured. The recently developed technique of X-Ray
Dual-Photon Absorptiometry (DPA) has been demonstrated to provide better
than 1% precision on measurements of the spine and the hip. These are the
preferred measurement sites because they are the most common sites to be
fractured as a result of low bone mineral content.

Single Photon Absorptiometry (SPA), the predecessor of DPA, measures
bone mineral content by passing a monochromatic beam of gamma rays
through the patient. The measured gamma ray attenuation can then be related
to the amount of bone mineral that the beam asses through. The significant
problem with SPA is that there is no effective way of separating attenuation
due to bone from attenuation due to soft tissue. This leads to errors in
accuracy and precision.

Dual Photon Absorptiometry was developed to better separate tissue from
bone. The instrumentation is similar to SPA, except a radionuclide is used that
emits photons at two distinct energy levels. The most commonly used
radioisotope is Gadolinium-153, which emits a group of gamma rays at about 44
Kev and another group at about 100 Kev. Bone attenuates the lower energy
photons much more than the higher energy ones. Soft tissue, on the other
hand, attenuates both energy levels about an equal amount. This differential
attenuation allows the separation of bone from soft issue. Two equations can
be written using the measured attenuation at the two energies. From these
two equations, the two unknowns can be found, namely the amount of soft
tissue and the amount of bone mineral.

Several methods have been suggested as to how to use an x-ray tube to
perform DPA. One approach is to shape the x-ray spectrum by use of a rare
earth filter. The beam exiting an x-ray tube contains x-rays of widely varying energies. Fig. 1. shows the spectrum of two x-ray beams after passing through filters containing rare earth elements. The high absorption of the rare earth K-edges have removed x-rays with energies near the center of the spectrum. This results in two clearly defined energy peaks. These two energy peaks can then be used in the same manner as the radionuclide scanners which use the two energy peaks of Gadolinium-153. The broken line in Fig. 1. was obtained for a Samarium filter at 90 KV x-ray tube operation, while the unbroken line is for Cerium at 80 KV. These two sets of operating parameters have both been used in DPA systems.

SYSTEM PERFORMANCE

In 1988, Lunar Radiation completed development of the Dual Photon X-ray (DPX) system. The DPX system is capable of whole body bone mineral scans as well as localized scans such as the spine and hip. Spine scans take approximately 4 minutes and require 1 mR patient dose. Spacial resolution is approximately 2 mm.

Several thousand scans on spine phantoms have shown a DPX precision of about 0.5%. Monte Carlo simulations have shown that this precision is limited by quantum statistics of the detected x-rays, implying that better precision can not be obtained without increasing the radiation dose. Several \textit{in vivo} spine studies have been completed on the DPX. As shown in Fig. 2, a normal 25 year old male volunteer was scanned daily over a period of 3 weeks. The measured precision of this study is 0.8%, which is typical of other \textit{in vivo} studies conducted. It should be noted that no drift is observable in the data over the three week measurement period. It should also be noted that the radiation dose received by the volunteer for the entire study was no more than for a standard chest x-ray. This combination of high precision and low dose allows repetitive measurements to detect bone mineral changes as low as 1 percent.

CONCLUSION

The fundamental processes of bone demineralization during weightlessness are poorly understood. Additional studies are required to insure the health and effectiveness of space flight crews. X-ray instrumentation developed during the last year has significantly improved the ability to measure bone mineral, and the resulting integrity of the skeletal system. The high precision and low radiation dose of this technique allows detection of bone mineral changes of less than 1% with examinations conducted directly at the anatomic sites of interest. This will allow the required bone mineral studies to be completed in a shorter time and with greater confidence.

REFERENCES


Fig. 1. Energy spectrum produced by rare earth filtration.

Fig. 2. Measured in-vivo precision of the DPX system.
PRESENTATION VIEWGRAPHS
INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

ABSTRACT

Proper instrumentation is key to the success of a spaceflight experiment. Development of proper instrumentation for a microgravity environment, especially under the constraints imposed by a manned vehicle, is a more difficult task than might be imagined. This presentation discusses the definition, design, development and testing of instrumentation, considers the requirements, interfaces and scope of instrumentation, and provides anecdotes gleaned by the Space Life Sciences Payloads Office from simulations and flights.
INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

SUB-TITLE: MURPHY WAS AN OPTIMIST!

INSTRUMENTATION:
Instrumentation is defined here broadly as all equipment required to support the experiment. When designing instrumentation, we (and hopefully the PI) consider requirements, interfaces and scope of instrumentation. While these are highly interactive considerations (PAYLOAD DEVELOPMENT VIEWGRAPH, VERIFICATION VIEWGRAPH), for the purposes of this presentation, they are discussed as discrete entities.

REQUIREMENTS:
While ground-based studies generally consider advertised (or needed) capability, availability and cost, we have additional requirements, and strongly consider (in addition to the usual science requirements) reliability, training and imposed requirements. Interaction of these in the space environment is much more extensive and apparent than in ground-based studies.

SCIENCE REQUIREMENTS:
Science requirements must consider not only the type of experiment to be performed, but the conditions (environment) under which it is performed, the number of subjects, and who is performing it (crew, unattended, unmanned). These aspects are generally well considered during the payload development process, but when they are not, major perturbations usually result. Anecdotes:

- Squirrel Monkey Feeder - Switch inadvertently disabled during S/L shutdown. No indicator.
- Urine Monitoring System - Airflow levels insufficient to control streams/boluses of water.
- Tissue Shipment - Properly packaged shipment went astray long enough for ice to "melt".
- Cell Culture System - Piston containment exerted too much pressure on cells.
INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

INSTRUMENTATION (Cont.):

RELIABILITY REQUIREMENTS:
No, you can't fix it at your bench! Reliability requirements consider not only whether the unit will perform the designated function, but also whether the unit will endanger other operations and the number of flights the unit is designed for. The review process for instruments/payloads is designed to help assure that nothing is missed. When something is, then - Anecdotes:
- Sea Urchin Handle - Hardware flimsy, poorly marked and incompletely tested. Limited training of crew for "carry-on". Result - Handle turned too far and equipment damaged; no results.
- Drop Dynamics Module - Failed on start-up. Crew spent most of mission on repair.
- Tissue Shipment - Properly packaged shipment went astray long enough for ice to "melt".

IMPOSED REQUIREMENTS:
Imposed requirements are generally of a nature to protect the crew, vehicle and other experiments. Violations of this nature (cleanliness, sharp edges, safety, ease of function, forbidden materials, etc.) prevent you from flying when discovered before launch. When discovered later, they are often major embarrassments. Anecdotes:
- Particulates on SL-3 - Animals produced more particulates, and air stream failed to control.
- Urine Monitoring System - See Science Requirements section.
- Monkey Door - Perforated door replaced with solid. Designer used same part number. Result - Door replaced by back-up, perforated door, and solemn assurance to Mission Manager violated.
INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

INSTRUMENTATION (Cont.):

REQUIREMENTS (Cont.):

TRAINING REQUIREMENTS:
Generally, you can't perform your own experiment. A surrogate (crew) has to do it. This means that the crewman must be as well-trained, or better trained than you. The best developed hardware is no better than the person operating it. Generally, sufficient training sessions are provided (MISSION APPROACH VIEWGRAPH). Anecdotes:

- Very Wide Field Camera - Scientific Airlock handle damaged; no results.
- Sea Urchin Handle - See Reliability Requirements section.
- Autogenic Feedback Training - Crew not sufficiently convinced of value; limited data.

INTERFACES:
Interfaces are defined here more broadly that those usually seen. For the purposes of this presentation, interfaces will be identified as defined, constrained and controlled. To use the current vernacular, if you don't interface, you are not part of the group (that flies).

DEFINED INTERFACES:
Defined interfaces are those you will find in the vehicle handbook (Spacelab Payload Accommodations Handbook). They include data, rack, power buss, telemetry, etc. interfaces. They are usually quite definitive and explicit, rarely contradictory, and often correct. Anecdotes:

- Rack Interfaces - Hand made, so therefore requires hand-fitting or slotted holes.
- Document Conflicts - What to do when you find them. and when you don't.
INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

INSTRUMENTATION (Cont.):
INTERFACES (Cont.):

CONSTRAINED INTERFACES:
Constrained interfaces are most often referred to as resources (power, weight, size, volume, crew time, data handling capability, etc.). If you do not consider them as constrained interfaces, you could be in trouble when developing hardware. In addition, they are often jello-like in spite of signed interface agreements. Anecdotes:

- Autogenic Feedback Training - Bulky waistpack limited usefulness; crew time requirements limited participation.
- ATMOS Vacuum Leak - SL-3 expts asked to give up/juggle operating time for ASTRO data.
- SLS-1/2 - Experiments de-manifested due to a combination of growth and oversubscription.

CONTROLLED INTERFACES:
Controlled interfaces come with the vehicle and include cabin pressure/temperature/humidity, gas composition, orientation, g-forces, access to vehicle, etc. They are usually very reliable until you rely on them. Then all sorts of interesting things happen. Anecdotes:

- Research Animal Holding Facility, Late Access - Mid-aisle transporter plus entry gantry became mid-aisle transporter plus Module Vertical Access Kit became mid-deck transporter with crew maneuver through tunnel became rack-mounted Module with MVAK servicing, and then they wanted to change from oxygen to nitrogen in Spacelab for better fire control.
- Ant Colony - Student Space Involvement Program. Ants perished on pad.
- Web Building - SSIP; Low humidity in S/L required crew to hand-feed spiders.
- RAHF - Low humidity in S/L could have contributed to particulate problem.
INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

INSTRUMENTATION (Cont.):

SCOPE OF INSTRUMENTATION:
Scope of instrumentation can be delineated as not enough, too much, wrong kind and just right. As with Science Requirements, the scope of instrumentation is often dictated by the type of experiment, the environment, sample size, and who is performing it (crew, unattended, unmanned). Included in this section would also be telescience operations.

NOT ENOUGH INSTRUMENTATION:
Most reporting from Spacelab is of the negative/confirmation variety. For the sake of the experiment, you want the experiment to provide the crew with sufficient information to determine if it is proceeding properly. For the sake of your psyche, you want sufficient information to make intelligent judgements on the progress of the experiment. However, a balance must be achieved between critical information, resources and extremely competent crew. Anecdotes:
- RAHF Monkey Feeder - See Science Requirements section. No indicator on ground, either.
- Problem Solving - No information, no solutions.

TOO MUCH INSTRUMENTATION:
Over-instrumented equipment increases probability of failure and over-utilizes valuable resources. Over-instrumented specimens can also be deadly with respect to the information obtained and with respect to the specimen. Anecdotes:
- RHESUS Project - Concern about loops and negative feed-back.
- Biosatellite III - Over-instrumentation of Bonnie could have been a factor.
INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

INSTRUMENTATION (Cont.):
SCOPE OF INSTRUMENTATION (Cont.):

WRONG KIND OF INSTRUMENTATION:
Considerable care must be given to the choice of instrumentation with regard to proper science support, with regard to crew and human factors considerations, and with regard to function in the unique environment of microgravity. Equipment which performs beautifully for you in ground-based experiments can be worthless in Spacelab. Anecdotes:
- Autogenic Feedback Training - Pack was bulky and got in the way; was not worn as scheduled.
- Cell Culture System - Cells adhered poorly; fluid shear displaced cells.
- KC-135 Flights - Provides ability to validate microgravity concepts with short-duration parabolas.

PROPER INSTRUMENTATION:
Non-existent state we all strive to obtain. Anecdotes:
- Future Hardware?
LIMITATIONS ON SCIENCE DUE TO MISSION CONSTRAINTS

RODNEY W. BALLARD, Ph.D.
NASA ARC
LATE/EARLY ACCESS

- LATE LOADING --
  - 18 TO 24 HOURS PRIOR TO LAUNCH
  - THIS MEANS AS MUCH AS 54 HOURS FROM LOADING TO SPACELAB ACCESS

- EARLY UNLOADING
  - 2 TO 4 HOURS AFTER LANDING
  - STS IS TALKING 24 HOURS FOR SAFETY REASONS

- ASCENT AND DESCENT
  - DATA ACQUISITION IS ALMOST IMPOSSIBLE
  - ELECTRICAL POWER IS VERY LIMITED
  - NO ACCESS POSSIBLE
CREW TIME

- LITTLE CREW TIME IS AVAILABLE FOR AN INDIVIDUAL EXPERIMENT
  - SELF-CONTAINED AND AUTOMATED EXPERIMENTS ARE ENCOURAGED
  - TELESCIENCE MAY OR MAY NOT BE AN ANSWER

- CREW MEMBER MAY NOT BE A SPECIALIST IN YOUR DISCIPLINE
  - CREW TRAINING IS ESSENTIAL
  - SIMPLE AND FOOLPROOF PROCEDURES YIELD THE BEST RESULTS
  - IF A HARDWARE FAILURE OCCURS, SIMPLE HARDWARE IS EASIEST TO FIX

- SAFETY IN SPACELAB IS ALL IMPORTANT
  - RADIOISOTOPES AND OTHER TOXIC MATERIALS MUST BE TRIPLE CONTAINED
  - SPECIAL FAILURE MODE ANALYSIS MAY BE REQUIRED
  - LIMITS ON TOXIC MATERIALS REGARDLESS OF CONTAINMENT
MISSION DURATION

- MISSION LENGTH SHOULD MATCH THE SCIENCE OBJECTIVES

  - STS MISSIONS WILL BE FROM 4 - 16 DAYS
    * ALL MID DECK OPPORTUNITIES ARE NOT THE SAME!

  - SPACELAB MISSIONS ARE TENDING TOWARD LONGER DURATIONS
    * THIS IS GOOD FOR CREW TIME, BUT NOT IF HARDWARE, CONSUMABLES OR SPECIMENS ARE NOT DESIGNED FOR THE MISSION LENGTH

  - LONGER MISSIONS MEAN EVEN MORE POWER RESTRAINTS
    * EVEN SHORT PERIODS OF HEAVY POWER MAY NOT BE ACCOMMODATED
GENERAL CONSTRAINTS

- LIMITED OPPORTUNITY FOR REPEAT EXPERIMENTS

- WEIGHT AND VOLUME RESTRICTIONS MEAN THAT THE LARGER THE ORGANISM THE SMALLER THE "N"

- BIOINSTRUMENTATION
  - IMPLANTS MUST BE DEMONSTRATED FOR SEVERAL MONTHS NOT JUST DURATION OF MISSION
  - DATA TRANSFER AND PROCESSING MAY BE LIMITING
  - WITH LIMITED NUMBERS OF SPECIMENS, HARDWARE FAILURES ARE MAGNIFIED
MISSION CONSTRAINTS ON HARDWARE DESIGN

- ABSTRACT -

A summary of Mission requirements is presented, including physical, safety, and operational constraints. A list of documentation and formal reviews is presented. The effects of hardware and operational changes are described.
MISSION CONSTRAINTS ON HARDWARE DESIGN

In addition to the scientific and performance requirements imposed by the Principal Investigator the hardware must meet various Mission requirements.

These mission requirements are imposed to protect the crew, the orbiter and other flight experiments on the same mission.

In addition to requirements imposed on the flight hardware, similar and in some cases identical requirements are imposed for hardware used in flight concurrent ground studies (Hangar L) and on ground support hardware used in conjunction with flight hardware.

This is by no means a complete listing of mission requirements, it is intended to give the experiment / hardware developer an inkling of what to expect. Many capable people are available to the Scientist and Hardware Developer to assist in the design, fabrication and documentation process necessary to qualify and fly experiment hardware.
I PHYSICAL CONSTRAINTS

A. SIZE, SHAPE, VOLUME, MASS DISTRIBUTION
   * MUST FIT INTO ASSIGNED ENVELOPE
     - SINGLE OR DOUBLE RACK
     - MID-DECK LOCKER
     - STOWAGE LOCKER
     - ETC.

B. MASS LIMITS
   * RACK STRUCTURAL LIMITATIONS
   * RACK DICTATED LIMITS FOR LOCATION OF CENTER
     OF GRAVITY
SINGLE RACK ENVELOPE
C. HARDWARE STRUCTURAL CAPABILITY

* HARDWARE MUST BE CAPABLE OF WITHSTANDING THE LAUNCH AND RECOVERY LOADS.
  - ANALYSIS AND TEST DATA MUST DEMONSTRATE THAT THE AS-BUILT HARDWARE'S STRUCTURAL CAPABILITY EXCEEDS THESE LOADS BY A POSITIVE MARGIN
* THE HARDWARE MUST BE CAPABLE OF WITHSTANDING ALL LOADS THAT MAY BE IMPOSED DURING TRANSPORT, OPERATION, ASSEMBLY, DISASSEMBLY AND STOWAGE
  - THE HARDWARE MUST BE CAPABLE OF WITHSTANDING ALL CREW-APPLIED LOADS.
    - LOADS EXPERIENCED DURING HARDWARE USE
    - INADVERTENTLY IMPOSED LOADS
      - "KICK-OFF" LOADS
        - HARDWARE FIXED TO IMMOVABLE STRUCTURES
    - LOADS IMPOSED BY TETHERS DURING ORBITER ACCELERATION / DECELERATION
C. STRUCTURAL CAPABILITY (continued)

- THE HARDWARE MUST BE CAPABLE OF WITHSTANDING THE Pressures DEVELOPED WITHIN THE HARDWARE DUE TO SPACELAB DEPRESSURIZATION / DEPRESSURIZATION / REPRESSION CURVE IS SPECIFIED IN THE SPACELAB ACCOMMODATIONS HANDBOOK (SPAH)

II. SAFETY

A. FLAMMABILITY, FLAME PROPAGATION, COMBUSTION PRODUCTS
   - TOXICITY
   - OFF-GASSING CONSTITUENTS

B. CONTAMINATION OF THE SPACELAB ENVIRONMENT
   - FIXATIVES
   - GROWTH MEDIA
   - EXPERIMENT LIQUID WASTE
   - SOLIDS, PARTICULATE MATTER
   - SOIL
   - FOOD BAR PARTICLES
   - EXPERIMENT SOLID WASTE
SAFETY (continued)

C. BIOHAZARDS
   * RADIOACTIVE TRACERS
   * CARCINOGENS
   * TOXIC SUBSTANCES

D. ELECTRICAL SHOCK
   * ANALYSIS AND TEST DATA MUST DEMONSTRATE THE ELECTRICAL SAFETY
     OF THE HARDWARE

E. EMI
   * ELECTROMAGNETIC INFLUENCES ON THE ORBITER AND OTHER EXPERIMENTS
     IS NOT PERMITTED.
     - ANALYSIS AND TEST DATA MUST DEMONSTRATE THAT THE HARDWARE
       DOES NOT RADIATE EMI BEYOND SPECIFIED, ACCEPTABLE LIMITS.

F. CREW INTERFACES
   * SHARP EDGES
   * LATCH DESIGN
     - PINCHED FINGERS
     - BUSTED KNuckles
     - HUMAN FACTORS
### III OPERATIONAL CONSTRAINTS

#### A. PRE-LAUNCH PREPARATIONS

* EXPERIMENT PREPARATION FOR LOADING, INCLUDING GROUND STUDIES, FLIGHT BACK-UPS
  - MINIMIZE LAST-MINUTE COMPLEXITY
  - MINIMIZE LAST MINUTE WORKLOAD
  - MINIMIZE NEED FOR COMPLEX LAB SUPPORT / HUMAN RESOURCES.

* LATE ACCESS: BEGINS AT LAUNCH MINUS 50 HOURS (MAY CHANGE) ENDS AT LAUNCH MINUS 13 HOURS
  - MINIMIZE PERISHABLE / CONSUMABLE EXPERIMENT CONTENT
  - MINIMIZE ENVIRONMENTAL CONTROLS NEEDED DURING LATE ACCESS LOADING
    - CARRY-ON CONTAINERS
  - MINIMIZE ENVIRONMENTAL CONTROLS NEEDED AFTER LOADING AND PRIOR TO POST-LAUNCH EXPERIMENT STARTUP
III OPERATIONAL CONSTRAINTS (continued)

A. PRE-LAUNCH (continued)
   - ORBITER / SPACELAB IN VERTICAL POSITION
     
     - PERSONNEL PERFORMING LATE ACCESS LOADING ARE LOWERED INTO SPACELAB BY BOSUN'S CHAIR
       - LATE ACCESS ITEMS SIZE LIMITED ACCORDINGLY
       - MASS IS LIMITED
       - COMPLEXITY OF LOADING OPERATION IS LIMITED
       - MAN ON THE FLYING TRAPEZE.
     
     - POST EXPERIMENT LOADING, PRE-LAUNCH OPERATIONS (ON THE PAD TIME)
       - VERY LIMITED UTILITIES AVAILABLE
       - VERY LIMITED DATA EXCHANGE CAPABILITY
         - EXPERIMENT SHOULD TAKE CARE OF ANY REQUIRED DATA ACQUISITION AND STORAGE.
     
     - LIMITED ENVIRONMENTAL CONTROLS
     - NO CREW INTERACTION WITH THE EXPERIMENT
III OPERATIONAL CONSTRAINTS (continued)

A. PRE-LAUNCH (continued)
   - LAUNCH DELAY
     - EXPERIMENT MUST ACCOMMODATE MAXIMUM LAUNCH HOLD
       WITHOUT REQUIRING SERVICES - 24 MAXIMUM DELAY
   - LAUNCH RESCHEDULE
     - REPLACE/REFURBISH/REPLENISH CAPABILITY
       - MUST BE READY TO FLY AGAIN WITHIN 72 HOURS

B. IN-FLIGHT
   - SPACELAB / ORBITER CLOSED ENVIRONMENT
     - LIMITED HEAT REMOVAL CAPABILITY
     - LIMITED ELECTRICAL POWER CAPACITY
       - ALLOW FOR CONTINGENCIES
     - LIMITED 'GARBAGE' VOLUME AVAILABLE
       - WHAT GOES UP MUST COME DOWN
III OPERATIONAL CONSTRAINTS (continued)

B. IN-FLIGHT (continued)

- NON GRAVITY ACCELERATIONS
  - ORBITER MANEUVERING/ATTITUDE CONTROL
    - RANDOM VECTORS
    - LIMITED SCIENCE CONTROL
      - MAKE NEEDS KNOWN EARLY ON
      - FACTOR INTO EXPERIMENT TIME-LINE
  - CREW IMPOSED ACCELERATIONS
    - VIBRATION
    - ADJACENT DOOR/DRAWER CLOSURE
    - INADVERTANT CREW IMPACT WITH HARDWARE

- ORBITAL INCLINATION
  - MISSION SPECIFIC
  - MANIFEST IN ACCORDANCE WITH EXPERIMENT REQUIREMENTS
III OPERATIONAL CONSTRAINTS (continued)

B. IN-FLIGHT (continued)
   - FIRST CREW ACCESS TO SPACELAB IS LAUNCH + 6 HOURS
   - LIMITED CREW TIME (60% FIRST DAY, 75% THEREAFTER)
     - USER FRIENDLY HARDWARE MAXIMIZES CREW PRODUCTIVITY
       - MINIMIZE ON-ORBIT COMPLEXITY
       - BDA
       - MINIMIZE THE NUMBER OF CREW OPERATIONS
       - MAXIMIZE EXPERIMENT SELF-SUFFICIENCY
         - OPERATION
         - DATA COLLECTION / CREW OBSERVATION
       - SEVERELY LIMITED ON-ORBIT REPAIR CAPABILITY
         - FEW TOOLS OR STOWAGE VOLUME FOR THEM
       - SEVERELY LIMITED TIME AVAILABLE FOR CREW/GROND
         INTERACTIVE DIAGNOSIS
         - COMPLETE MALFUNCTION PROCEDURES ESSENTIAL
         - NO "BEAM ME UP SCOTTY" CAPABILITY AVAILABLE AT THIS TIME
     - THE BOTTOM LINE:
       - ON-ORBIT OPERATIONAL SIMPLICITY AT THE EXPENSE OF PRE-FLIGHT
         COMPLEXITY IS A GOOD TRADE-OFF
       - SIMPLICITY - SIMPLICITY - SIMPLICITY
III OPERATIONAL CONSTRAINTS (continued)

- C. POST FLIGHT
  - RECOVERY TIMES
    - PRIME LANDING SITES
      - KSC
      - DRYDEN
        - 3 HOUR MINIMUM WAIT FOR ACCESS TO THE EXPERIMENTS
          - LIKELY TO INCREASE TO 24 HOURS PLUS
            - NO CREW INTERACTION
            - LIMITED UTILITIES
            - PROVIDE / SPECIFY NEEDED RECOVERY CONTROLS
              - ENVIRONMENTAL
              - ORIENTATION CONTROLS / SPECIAL HANDLING
              - MINIMIZE TIME-CRITICAL OPERATIONS
    - CONTINGENCY LANDING SITES
      - LENGTHY RECOVERY DELAYS
      - VERY LIMITED GROUND CREW / ORBITER SERVICING EQUIPMENT AVAILABLE
        - PROVIDE CONTINGENCY PLANS/PROCEDURES TO MITIGATE SCIENCE LOSS
IV DOCUMENTATION REQUIREMENTS

- DOCUMENTATION MATURITY:
  - PRELIMINARY DESIGN REVIEW (PDR)
    - HARDWARE PERFORMANCE REQUIREMENTS FROZEN /BASE-LINED
    - HARDWARE CONCEPTS ESTABLISHED
    - PRELIMINARY DRAWINGS COMPLETED AFTER INCORPORATION OF PDR COMMENTS
    - PERMISSION TO PROCEED AS BASELINE D GRANTED
    - FINAL DESIGN AND DOCUMENTATION GENERATION STARTED
  - CRITICAL DESIGN REVIEW (CDR)
    - BUILD-TO DRAWINGS REVIEWED AND APPROVED
    - DESIGNS REVIEWED AND ACCEPTED
    - DESIGN IS BASELINED
    - DRAWINGS FROZEN FOLLOWING INCORPORATION OF CDR COMMENTS
    - CHANGE CONTROL INVOKED
      - CHANGES FROM THIS POINT REQUIRE CHANGE CONTROL BOARD APPROVAL
    - PERMISSION TO PROCEED WITH HARDWARE FABRICATION GRANTED
    - PAYLOAD DOCUMENTATION UPDATED
IV  DOCUMENTATION REQUIREMENTS  (continued)

- INTEGRATED PAYLOAD CRITICAL DESIGN REVIEW

- MISSION PAYLOAD IS BASELINED

  - POST IPL/CDR CHANGES IMPACT:

    - GROUND INTEGRATION REQUIREMENTS DOCUMENT
    - INSTRUMENT INTERFACE AGREEMENT
    - OPERATIONS AND INTEGRATION AGREEMENT
    - INTEGRATED PAYLOAD REQUIREMENTS DOCUMENT
    - EXPERIMENT REQUIREMENTS SIMULATION DOCUMENTATION
    - STOWAGE LIST
    - MANY OTHER DOCUMENTS
      - TEST PROCEDURES
      - STOWAGE DRAWINGS
      - MASS PROPERTIES REPORTS
      - ENGINEERING DRAWINGS
      - MATERIALS USAGE LIST

- GENERAL RULE : THE LATER A CHANGE IS REQUESTED THE LESS CHANCE
  THE CHANGE HAS OF BEING APPROVED.
SUMMARY

THE MAJOR CONSTRAINTS CAN BE GROUPED AND CLASSIFIED AS FOLLOWS:

1. PHYSICAL CONSTRAINTS
   HOW BIG
   HOW HEAVY
   HOW MANY RESOURCES ARE NEEDED

2. SAFETY CONSTRAINTS
   DOCUMENTATION AND TESTING MUST ASSURE THAT NO HARM WILL COME TO
   THE CREW OR ORBITER UNDER ANY FAILURE MODE.

3. OPERATIONAL CONSTRAINTS
   THE CREW HAS LIMITED TIME, AND RESOURCES AND IS OPERATING UNDER
   UNUSUAL CONDITIONS. (MICRO G)

4. DOCUMENTATION CONSTRAINTS
   FINALIZE REQUIREMENTS AS SOON AS POSSIBLE
   FINALIZE DOCUMENTATION AS SOON AS POSSIBLE

THE BOTTOM LINE: KEEP HARDWARE SMALL, LIGHT, MINIMIZE COOLING AND POWER USE
KEEP IT SIMPLE TO OPERATE AND MAKE IT AS SELF SUFFICIENT AS POSSIBLE
WORKING GROUP COMMERCIAL LIFE SCIENCE
ADVOCACY FLOW DIAGRAM

INTERNAL

EXTERNAL

OUTREACH TEAM
- Research Triangle Institute
- Boeing-PEAT Marwick
- Center for Space and Advanced Technology

CCDS
- Bioserve Space Technologies
- Center for Cell Research (CCR)

OTHER USERS
- Industrial Applications Centers
- Individual Companies
COMMERCIAL LIFE SCIENCE WORKING GROUP
ADVOCACY FOCAL POINTS

Workshops

Background And Status

- Summer 1988 Workshop in California
- Fall 1988 Sub-Panel at Denver Space Station Workshop
- Winter 1988 Workshop at Kennedy Space Center
COMMERCIAL LIFE SCIENCE WORKING GROUP
ADVOCACY FOCAL POINTS
OVERVIEW

- Developing and Implementing A NASA Research Announcement in Commercial Life Sciences

- Getting More Mileage Out of Small Business Innovation Research Awards In Life Sciences

- Providing a Focus for Space Station Mission Requirements in Commercial Life Sciences

- Continuing to Support Commercial Life Science Workshops
COMMERCIAL LIFE SCIENCE WORKING GROUP
ADVOCACY FOCAL POINTS

NASA Research Announcement in Commercial Life Sciences

Proposed Program Goal and Objectives

GOAL

Based on a partnership between OCP and the Life Sciences Division, use the
NRA as a mechanism to stimulate commercial investment and involvement
in ground and space-based life science initiatives which support NASA's long-
term life sciences program goals.

OBJECTIVES

• Stimulate commercially-sponsored basic research in commercial life
  sciences

• Increase the profile of NASA's life science program with U.S. industry, and
  stimulate the number of opportunities for industry to exploit unique NASA
  expertise and facilities in life sciences

• Build upon the partnerships which have been established between NASA,
  industry and universities in life sciences (e.g. Centers for the Commercial
  Development of Space)

• Provide the life sciences program at NASA with greater feedback on
  commercial user requirements
COMMERCIAL LIFE SCIENCE WORKING GROUP
ADVOCACY FOCAL POINTS

NASA Research Announcement in Commercial Life Sciences

Background

- Jointly Funded (Code C/Code EE) NASA Research Announcement for the Remote Sensing Applications/Commercialization Program

- OCP New Initiatives Task Team Life Sciences Sub-Panel Recommendation in Support of NRA in Commercial Life Sciences

- Industry Workshops in Life Sciences Sponsored by the Commercial Life Sciences Working Group
COMMERCIAL LIFE SCIENCE WORKING GROUP
ADVOCACY FOCAL POINTS

NASA Research Announcement in Commercial Life Sciences

Potential Research Areas

- Controlled Ecological Life Support Systems
- Biospherics
- Gravitational Biology
- Bioprocessing
- Biomedical Research
COMMERCIAL LIFE SCIENCE WORKING GROUP
ADVOCACY FOCAL POINTS

Small Business Innovation Research

Background

- Inclusion of Commercial Life Sciences Sub-Topic in SBIR Solicitation

- Participation of Life Sciences CCDS' in SBIR Proposals

- OCP New Initiatives Task Team Recommendations to Strengthen SBIR Support of Commercial Life Sciences Initiatives
COMMERCIAL LIFE SCIENCE WORKING GROUP
ADVOCACY FOCAL POINTS

Small Business Innovation Research

Objectives

• Implement OCP Task Team Life Sciences Sub-Panel Recommendations on Commercial Life Sciences:

  - Incentivize SBIR Awardee Collaboration with Industry to Facilitate Transition to Phase III Funding;

• Increasing the Number of SBIR Awardees in Commercial Life Sciences

• Provide Dedicated SBIR Selection in Commercial Life Sciences At Each Field Center
COMMERCIAL LIFE SCIENCE WORKING GROUP
ADVOCACY FOCAL POINTS

Serving As A Focus for Mission Requirements

Background And Status

- Commercial Life Sciences Working Group Originally Chartered as a Mechanisms for Generating Space Station Mission Requirements

- CLSWG Has Provided OCP (CD/Oran) With "Placeholder" Commercial Life Sciences Missions

- CLSWG Working With MSFC/Fountain to Input Commercial Life Science Requirements Into Space Station Payload Manifest
HERE WE GO...

EMERGING INDUSTRY COLLABORATION

EXPANDED OCP SUPPORT

STRONG ACADEMIC FOUNDATION
ACCOMPLISHMENTS

- ORGANIZED COMMERCIAL LIFE SCIENCES WORKING GROUP
- FACILITATED SELECTION OF TWO CCDs IN LIFE SCIENCES
- CREATED COMMERCIAL LIFE SCIENCES SBIR SUB TOPIC
- IDENTIFIED COMMERCIAL LIFE SCIENCE INITIATIVES FOR OCP TASK TEAM
- FIRST COMMERCIAL LIFE SCIENCES SUB PANEL
  - 1988 SPACE STATION FREEDOM WORKSHOP
PURPOSE OF SUB-PANEL

- DESCRIBE NASA'S LIFE SCIENCE PROGRAM AND POTENTIAL AREAS FOR COLLABORATION.
- DISCUSS MECHANISMS AVAILABLE FOR INDUSTRIAL COLLABORATION
- STIMULATE DIALOGUE ON HOW NASA CAN RESPOND TO INDUSTRY'S RESEARCH AGENDA IN LIFE SCIENCES
AMES SUPPORT FOR
COMMERCIAL LIFE SCIENCE RESEARCH

• ACCESS TO NASA INVESTIGATORS AND FACILITIES
  - SCIENTISTS AND ENGINEERS PERFORMANCE EVALUATIONS
  - AGREEMENT MECHANISMS

• SMALL BUSINESS INNOVATION RESEARCH PROGRAM
  - SUB TOPIC ESTABLISHED
  - 2 PHASE I AWARDS IN FY 88

• BIOSERVE, UNIVERSITY OF COLORADO BOULDER
  - CONTROLLED GRAVITY TECHNOLOGY, 1.8 METER CENTRIFUGE
  - MEMBER COMMERCIAL LIFE SCIENCE WORKING GROUP

• CENTER FOR CELL RESEARCH, PENN STATE
  - ANIMAL ENCLOSURE MODULE
  - MEMBER COMMERCIAL LIFE SCIENCE WORKING GROUP

• UNIVERSITY OF WISCONSIN, MADISON, WISCONSIN
PRELIMINARY LISTING OF CENTERS FOR THE COMMERCIAL DEVELOPMENT OF SPACE CORPORATE AFFILIATES

AMOCO CHEMICALS CORPORATION
PPG INDUSTRIES, INC.
ROCKWELL INTERNATIONAL
E.I. DUPONT
II-VI, INC.
HERCULES
BOEING AEROSPACE COMPANY
FRONTIER RESEARCH
DEERE AND COMPANY
IBM ALMADEN
MARTIN MARIETTA AEROSPACE
MCDONNELL DOUGLAS CORP.
TELEDYNE BROWN ENGINEERING
WYLE LABORATORIES
MASSCOMP
INTERNATIONAL PAPER
SOIL TECH, INC.
EXXON
MURPHY OIL
FREEPORT MC MORAN
APPLE COMPUTERS
HARDING LAWSON & ASSOCIATES
PALEN FARMS, INC.
GEOSTAR, INC.
VERSATEC
PIONEER SEED COMPANY
TENNECO OIL COMPANY
BRITISH PETROLEUM
FIRST NATIONAL BANK OF TONKAWA
BANK OF WELLS TONKAWA
ASTRONAUTICS CORP. OF AMERICA
AT&T
SCHERING CORP.
PROCTOR & GAMBLE
DOW CHEMICALS
SMITH, KLINE & BECKMAN
ELI LILLY
MERCK, SHARPE & DOME
UPJOHN
EASTMAN KODAK

BIOCRYST
ALCOA
ARMCO, INC.
ALLIED SIGNAL
CABOT, CORP.
ENGLERHAARD CORP.
GENERAL ELECTRIC
GENERAL MOTORS
GTE
LOCKHEED
GRUMMAN CORP.
TRANS-TEMP
WESTINGHOUSE
DANTEC ELECTRONICS
QUANTUM TECHNOLOGIES
BARNES ENGINEERING
SPACEHAB
SPECTRON LABORATORIES
ELECTRO-OPTIK
PERKIN ELMER
INSTRUMENTS S.A., INC.
BEAVER DAM EMERGING GROWTH
GAMMEX, INC.
DELCO
JOHNSON CONTROLS, INC.
MADISON KIPP, INC.
PHYTO FARMS OF AMERICA
PIERSON PRODUCTS, INC.
SILICON SENSORS
SNAP-ON-TOOLS
SUNDSTRAND CORP.
SEVRAIN TECH, INC.
AMERICAN ELECTRIC POWER COMPANY
TRIMBLE NAVIGATION
GAS RESEARCH INSTITUTE
SYNERCOM, INC.
DEC
3M
GOODYEAR
TRW

EDISON POLYMER INNOVATION
DOVAL COMPOSITES, INC.
LEMONT SCIENTIFIC, COMPANY
COULTER
SUPELCO
SCIENTIFIC SYSTEMS, INC.
ZETACHRON
MONOCLONAL PRODUCTION
DIGENE
SCIENTIFIC ENTERPRISES
ELECTROPORE, INC.
BEND RESEARCH
GELMAN SCIENCES
MICKLEY & ASSOCIATES
PRECISION SCIENTIFIC
BALL AEROSPACE
ALZA
MAXWELL LABORATORIES
ROCKETDYNE
SATURN CORP.
SYMBOLICS, INC.
TECHNION, INC.
PEPCO
GULF STATE UTILITIES
ENTECH, INC.
ARTHUR D. LITTLE
FORD AEROSPACE
SOLAR ENERGY RESEARCH INSTITUTE
ELECTRIC POWER RESEARCH INSTITUTE
COMSAT CORP.
EAGLE Picher, INC.
E-SYSTEMS, INC.
GENERAL DYNAMICS
ELECTROCHEM, INC.
FAIRCHILD
KMS FUSION
GEOSPECTRA, INC.
DUPRON, INC.
INVITRON

119 CORPORATE
CENTERS FOR THE COMMERCIAL DEVELOPMENT OF SPACE
CURRENT STATUS

- 32 UNIVERSITY PARTICIPANTS
- 119 INDUSTRIAL BUSINESS PARTICIPANTS
- IDENTIFIED 129 PRODUCTS/PRODUCT CATEGORIES
- 615 DROP TUBE/TOWER EXPERIMENTS
- 21 KC-135 FLIGHT EXPERIMENTS
- 1 SERIES OF LEAR JET FLIGHTS
- 4 STS FLIGHTS
- 5 EXPERIMENTS PREPARED FOR FIRST SOUNING ROCKET FLIGHT
- SMALL BUSINESS PARTICIPATION BEING DEVELOPED FOR SMALL BUSINESS INNOVATION RESEARCH AWARDS
OBJECTIVE

- PROVIDE THE PATHWAY FOR U.S. INDUSTRY TO DEVELOP LEADERSHIP IN THE COMMERCIAL USE OF SPACE
  -- DEVELOPING PROGRAMS THAT FOSTER NEW TECHNOLOGY DEVELOPMENT
  -- DEVELOPING PROGRAMS THAT LEAD TO NEW COMMERCIAL PRODUCTS

GENERAL CRITERIA

- NEW AND UNIQUE TECHNOLOGY DEVELOPMENT AND SYSTEMS LEADING TO COMMERCIAL USE OF THE SPACE ENVIRONMENT

- HIGHLY SPECIALIZED UNIVERSITY BASED CENTERS TO HELP U.S. INDUSTRY FOCUS ON TECHNOLOGY DEVELOPMENTS THAT ARE COMMERCIALLY-ORIENTED

- SYSTEMATIC EVOLUTION OF CENTERS TO BECOME HIGHLY INDEPENDENT OF NASA THROUGH THEIR DEVELOPMENT OF INDUSTRIAL COMMITMENT
OFFICE OF COMMERCIAL PROGRAMS

COMMERCIAL DEVELOPMENT DIVISION
D. OTT (DIRECTOR)
R. WHITTEN (DEPUTY)
P. ELLIS (SECRETARY)
J. GROSS (SECRETARY)

MARKET DEVELOPMENT BRANCH
R. WHITTEN (ACTING)
J. BROWN

COMMERCIAL AGREEMENTS BRANCH
J. YADVISH (CHIEF)

VENTURE LIAISON BRANCH
G. MISENER (CHIEF)
A. VILLAMIL
EXECUTIVE AND LEGISLATIVE BRANCH PRONOUNCEMENTS IN SUPPORT OF COMMERCIAL SPACE

"We will soon implement a number of executive initiatives, develop proposals to ease regulatory constraints, and with NASA's help, promote private sector investment in space."

State of the Union Address, 1984

"In the zero gravity of space, we could manufacture in 30 days life saving medicines it would take 30 years to make on Earth. We can make crystals of exceptional purity to produce super computers, creating jobs, technologies and medical breakthroughs beyond anything we ever dreamed possible."

State of the Union Address, 1985

"The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration seek and encourage to the maximum extent possible, the fullest commercial use of space."

Public Law 98-361, 1984

MAINTAINING AND ENHANCING U.S. LEADERSHIP IN COMMERCIAL SPACE ACTIVITIES
CONCLUSIONS/CLOSING REMARKS

Robert S. Bandurski and Paul Todd

This conference marks a watershed between the period when space was being tested for safety and the new period in which space is regarded as an important adjunct to our studies of biological, physical, and chemical phenomena. It was implicit in the numerous presentations and discussions that there will be increasingly frequent opportunities for experimentation in space, that generic hardware will facilitate the performance of space experiments, and that there will be commercial utility to space. Most importantly, there was a melding of physical and biological knowledge and an emphasis on how the weak forces of gravity are able to affect organisms composed of covalent and non-covalently bonded molecules.

It was correctly observed during the conference that it is the life forms that have developed, evolved, and grown on earth that constitute the 1-g experiment. The micro-g, and fractional-g controls attainable in space have, in general, rarely been done. We are now ready to study the micro-g controls and, for the first time, to understand the effects of 1-g.

This conference has convinced us that complex biological systems will greatly contribute to our knowledge of the physics of gravity.
CONFERENCE DEDICATIONS

Professor George Nace

(Provided by Kenneth Souza)

George Nace was born in 1920 in Cogsville, Pennsylvania. His parents were missionaries in Japan where, in his early childhood, he developed fluency in Japanese. During the second World War he was actively engaged for 2-3 years as an interpreter with the occupation forces where his fluency in Japanese was valuable. After his early years in Japan he came back to the United States, where he attended Reed College in Oregon and earned a degree in Biology. He then went to UCLA and obtained his masters and doctoral degrees in Zoology. Following a few years doing post-doctoral work, he joined the staff at the University of Michigan in 1957, where he remained until 1984 when he retired as Professor Emeritus. He died in 1987.

It was during his tenure at University of Michigan, that I first became acquainted with him and his involvement in the frog rearing and culturing activities. He was a great proponent of ecological studies of amphibia and an expert in their nurturing and rearing in the laboratory. By carefully controlling the environment in which the amphibia were reared, Professor Nace could guarantee the quality of specimens for the investigator. When \textit{Rana pipiens} became difficult to obtain because of over-collection during the 1960's and 70's, he became a supplier in every sense of the word. He founded his own company and had facilities where he developed a feeding technique which enabled him to raise \textit{Rana pipiens} through metamorphosis to the adult stage. A 1985 issue of \textit{Science} magazine featured Professor Nace and described his forte: the culture and rearing of a wide variety of "designer" amphibia or genetically-marked strains.

In 1978 Professor Nace joined with John Tremor, Muriel Ross and me to develop the Frog Embryology Experiment now scheduled to fly on Spacelab J. While he remained a member of the Frog Embryology experiment his primary focus was on teaching, particularly in teaching students to convey the message that amphibia could be raised in the laboratory setting. Some of his students returned to Korea and Japan where, as a consequence, he came to be a recognized and respected expert in amphibian biology. Over the past two decades Professor Nace served on a variety of NASA advisory committees and working groups. He was one of the first space biologists to recognize the need to include physicists in the analysis of microgravity experiments. It was during collaboration with a few physicists at the University of Michigan that Professor Nace developed what he called the torsional model of gravitational effects on the cell. The subject and focus of this event is a tribute to some of the insights and ideas of Professor Nace. I am pleased to dedicate this conference to him.

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**Professor Per F. Scholander**

*(Provided by Robert S. Bandurski)*

The Cells in Space Conference deals with the most exciting voyage on which humans have yet embarked -- the voyage into space. Thus, it is singularly appropriate that this conference be dedicated to Professor Per F. (Pete) Scholander -- a pathfinder of the first order. He knew that opportunities to understand life processes lie at the fringes of our environment--where living creatures face extremes of cold and heat, of wet and dry, of salty and salt free. He realized that it was at these extremes that life would most vividly reveal its secrets. Of all scientists he would have shared our excitement at the prospects of this journey into space.

Scholander was Professor Emeritus of Physiology and the first Director of Scripp’s Physiological Research Laboratory. He was born in Orebo, Sweden on November 29, 1905, and moved to Norway at an early age. He received his Doctorate in Medicine from the University of Oslo, Norway, in 1932 and the Doctorum Honoris Causa from Uppsala in 1977. He was elected to the National Academy of Sciences and the American Philosophical Society. He died on June 13, 1980, in La Jolla, a suburb of San Diego, California, at the age of 74.

Scholander had many research accomplishments usually characterized by the use of extraordinarily simple equipment, often built by himself, and capable of use in the extreme environments of the field. These included the Wick Technique for measurement of fluid pressures in animals and the Pressure Bomb for measuring solute osmotic pressures in plants. He was fascinated by the problem of getting water to the top of tall trees and, in this connection, used a rifle to shoot down branches from 100-meter-tall trees so their osmotic pressures might be measured. He investigated blood circulation and respiratory problems in diving animals, particularly the physiological mechanisms which act to prevent oxygen deficiency in brain tissue. He studied bradycardia, the cutting off of peripheral circulation, which developed in mammals upon submersion in water, or in fish upon removal from water. He studied climatic adaptations in arctic and tropical animals and the dynamics of negative tissue-fluid pressures in animals. He advanced the idea that an anti-freeze substance is present in fish living in polar waters and was among the first to analyze the composition of gas bubbles in glacial ice to determine atmospheric conditions in ancient times.

Professor Scholander was responsible for obtaining funds from the National Science Foundation for building and operating the Alpha Helix--the world’s first floating physiological biochemistry laboratory. The Alpha Helix, in addition to well-equipped laboratories, had an ice breaking prow and the stern of a Norwegian Whaler to carry scientists to the extremes of the world’s climatic conditions.

How fitting that we should also dedicate this conference to Professor Scholander. We hope that memories of his vision will accompany us into the environs of space.
ATTACHMENTS
ATTACHMENT A

CELLS IN SPACE-II
CONFERENCE PARTICIPANTS

Dr. Rodney Ballard
NASA/Ames Research Center
Mail Stop N240A-3
Moffett Field, CA 94035
(415) 694-6748

Dr. Robert Bandurski
Department of Botany
Michigan State University
East Lansing, MI 48824
(517) 355-4685/6589
FAX (517)353-1926

Dr. Thomas Björkman
Department of Botany
KB-15 University of Washington
Seattle, WA 98195
(206) 543-3944

Dr. Allan Brown
Gravitational Plant Physiology Lab
3401 Market Street
Suite 350
Philadelphia, PA 19104
(215)898-4908

Dr. Carlo Bruschi
Biotechnology Laboratory
East Carolina University
School of Medicine
Greenville, NC 27585-4354
(919) 551-3131

Dr. Paul X. Callahan
NASA/Ames Research Center
Mail Stop N240A-3
Moffett Field, CA 94035
(415) 694-6046

David K. Chapman
Gravitational Plant Physiology Lab
3401 Market Street
Suite 350
Philadelphia, PA 19104
(215)898-4908

Dr. Leonard Cipriano
LESC
Ames Research Center
Mail Stop N240A-4
P.O. Box 168
Moffett Field, CA 94035
(415) 694-6820

Dr. Donald Clifford
McDonnell Douglas Astronautics
P.O. Box 516
Bldg. 101A, Level 3, Room 340E
St. Louis, MO 63166
(314) 232-2896

Dr. Augusto Cogoli
Institute of Biotechnology
ETH-Hönggerberg
Ch 8093-Zurich
411-372-3683
FAX 411-372-0974

Dr. Gary W. Conrad
Bioserve Research Program - Ackert Hall
Kansas State University
Manhattan, KS 66506
(916)532-6662
Dr. Charles W. Lloyd  
Health Maintenance Facility  
Subsystem Management  
Krug International  
Houston, TX

Dr. Marvin Luttges  
Bioserve Research Program  
University of Colorado  
Campus Box 429  
Boulder, CO 80309  
(303) 492-7613 or 7713

Richard Mains  
Mains Associates  
2039 Shattuck Avenue  
Suite 402  
Berkeley, CA 94704  
(415) 548-1261

Dr. Andrea M. Mastro  
Professor of Microbiology & Cell Biology  
431 S. Frear  
Penn State University  
University Park, PA 16802

Rich McKenna  
LESC  
Ames Research Center  
P.O. Box 168  
Moffett Field, CA 94035  
(415) 694-6797

Laurance Milov  
External Relations Office  
NASA/Ames Research Center  
Mail Stop N223-3  
Moffett Field, CA 94035

Helene Najduk  
External Relations Office  
NASA/Ames Research Center  
Mail Stop N223-3  
Moffett Field, CA 94035  
415-694-4034

Dr. Arthur J. Olson  
Research Institute of Scripps Clinic  
10666 N. Toy Pines Road  
LaJolla, CA 90237  
(619) 554-9702

Dr. Delbert Philpott  
NASA  
Ames Research Center  
M/S 239-14  
Moffett Field, CA 94035

Yvonne Russell  
Russmark, Inc.  
602 Stendahl Lane  
Cupertino, CA 95014  
(408) 252-8316

Dr. Ron Schaefer  
LESC  
Ames Research Center  
Mail Stop N240A-4  
Moffett Field, CA 94035  
(415) 694-4438

Teri Schnepp  
Lockheed Missiles and Space Co.  
M/S 0-53-51  
Building 580  
Sunnyvale, CA 94088  
(408) 756-5940  
(408) 742-6139

Dr. P. K. Seshan  
Jet Propulsion Laboratory  
Mail Stop 125-112  
4800 Oak Grove Drive  
Pasadena, CA 91109  
(818) 354-7215

Dr. Jean D. Sibonga  
Mains Associates  
1076 College Avenue  
Palo Alto, CA 94306  
(415) 493-9441
Dr. Steven Smith  
Future Research  
4310 South Main St.  
Murray, UT 84107  
(801) 268-8832

Dr. Karam F. A. Soliman  
Dept. of Pharmacology  
Rm. 104, Dyson Building  
Florida A & M University  
Tallahassee, FL 32307  
(904)599-3306

Dr. Michael Solursh  
Department of Zoology  
University of Iowa  
Iowa City, IA 52242  
(319) 335-1058

Dr. Gerald Sonnenfeld  
Dept. of Microbiology & Immunology  
University of Louisville School of Medicine  
Health Sci Center  
Louisville, KY 40292  
(502) 588-6323

Kenneth Souza  
NASA/Ames Research Center  
Mail Stop N240A-3  
Moffett Field, CA 94035  
(415) 694-5736

Dr. Barry Taylor  
Loma Linda Medical School  
School of Medicine  
Department of Microbiology  
Loma Linda, CA 92350  
(714)824-4480

Dr. Paul Todd  
National Institute of Standards & Technology  
Center for Chemical Engineering 583.10  
325 Broadway  
Boulder, CO 80303  
(303)497-5563

Dr. John Tremor  
LESC  
Ames Research Center  
Mail Stop N240A-4  
P.O. Box 168  
Moffett Field, CA 94035  
(415)694-6820

Dr. Steve J. Upton  
Bioserve Research Program  
Kansas State University  
Manhattan, KS 66506

John Vellinger  
Space Hardware Optimization Technology  
922 Rochester Street  
Lafayette, IN 47905  
(317)474-4986

Dr. Howard Wachtel  
Engineering Center  
Campus Box 425  
University of Colorado  
Boulder, CO 80309

Dr. Lynn Wiley  
California Primate Research Center  
University of California  
Davis, CA 95616  
(916)752-8421

Dr. Charles Winget  
NASA/Ames Research Center  
Mail Stop N240A-3  
Moffett Field, CA 94035  
(415)694-5753
ATTACHMENT B

CELL RESEARCH EXPERIMENTS
(FLOWN/PLANNED)

1. Plant/Animal Cell Cultures
2. Oocyte/Embryo Development
3. Microorganisms

The following tables provide a recent collection of space cell research experiments that have flown, or are planned. The experiments were obtained from a selected literature search and are divided into three groups: Plant/Animal Cell Cultures, Oocyte/Embryo Development, and Microorganisms.

Information provided in the tables includes: the name of the experiment, the mission on which it was flown/planned and the year, a brief description of the flight hardware, and a reference source (see Attachment D). In addition, the table for Plants/Animal Cell Cultures provides the organism used for the culture. The experiments are arranged in ascending order according to the date of the mission and each has been assigned a number for references purposes.

Several experiments refer the reader to the Cell Research Flight Hardware descriptions in Attachment C (obtained from references in Attachment D).
## 1. Plant/Animal Cell Cultures

<table>
<thead>
<tr>
<th>#</th>
<th>EXPERIMENT</th>
<th>ORGANISM</th>
<th>FLOWN/PLANNED</th>
<th>HARDWARE</th>
<th>REF.</th>
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<td>A1</td>
<td>The Effects of Space Flight on Living Human cells - Chicken embryo tissue</td>
<td>Discoverer XVIII ('60)</td>
<td>Glass ampoules, salt solution, 10% horse serum, refirg. units, neutron film pack, chem. dosimeters, gold foil, glass needle sets, 552 film strips, polyethylene foam (packing), alanine pcts, 1 step plate &amp; film, nuclear track plates</td>
<td>(1) p. 121</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>Exposure to Spaceflight</td>
<td>Hela Cultures</td>
<td>Sputnik 4 ('60)</td>
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<td>(5) pp. 36-37</td>
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<td>Sputnick 6 ('61)</td>
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<td>(5) pp. 36-37</td>
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<td>Sputnik 7 ('61)</td>
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<td>(5) pp. 36-37</td>
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<td>Exposure to Spaceflight</td>
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<td>Exposure to Spaceflight</td>
<td>Hela culture</td>
<td>Yoskhod-2 ('65)</td>
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<td>(5) pp. 36-37</td>
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<tr>
<td>A8</td>
<td>Radiation and Zero-G Effects on Human Leukocytes and Neurospora crassa</td>
<td>Gemini 3, 11('65, '66)</td>
<td>32P source, alum. blood-sample holder, dosimeter rods</td>
<td>(1) p. 155</td>
<td></td>
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<tr>
<td>A9</td>
<td>Radiobiological Studies of Tradescantia Plants Orbited</td>
<td>Plant Tradescantia Biosat II ('67)</td>
<td>Expt pocks of polypropylene plastic to hold 32 plants with nutrient solution thermistor, dosimeters</td>
<td>(1) p. 152</td>
<td></td>
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<td>A10</td>
<td>Exposure to Spaceflight</td>
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<td>Zond5 ('58)</td>
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<td>(5) pp. 36-37</td>
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<td>A11</td>
<td>Cell Growth in &quot;Bioterm&quot;</td>
<td>Cells from Syrian hamster (strain VNK-21)</td>
<td>Kosmos 368 ('70)</td>
<td>Bioterm apparatus temp. control</td>
<td>(5) pp. 36-37</td>
</tr>
<tr>
<td>A12</td>
<td>Effects of ZeroG on living cells</td>
<td>Human embryonic lung cells (WI-38)</td>
<td>Skylab 3 ('73)</td>
<td>Woodlawn Wanderer 9. See Hardware Section 1.</td>
<td>(2) p. 221</td>
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<tr>
<td>A13</td>
<td>Cytoplasmic Streaming</td>
<td>Water weed (Elodea)</td>
<td>Skylab 3, 4 ('73)</td>
<td>Vials, microscope slides, cover slips, tweezers, microscope, microscope camera adapter, 16mm motion picture camera</td>
<td>(1) p. 149</td>
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<td>A14</td>
<td>Electrophoresis Experiment MA014</td>
<td>rat bone marrow, spleen, lymph node cells with</td>
<td>Apollo Soyuz</td>
<td>Separation chamber consisting of 2 cooling plates, Electrodes</td>
<td>(1) p. 111</td>
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<tr>
<td></td>
<td></td>
<td>addition of human erythrocytes as markers and</td>
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<td></td>
<td></td>
<td>a mixture of human and rabbit erythrocytes</td>
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<tr>
<td>A15</td>
<td>Electrophoresis Tech. MA011</td>
<td>Human, rabbit, &amp; horse erythrocytes</td>
<td>Apollo Soyuz</td>
<td>electrophoresis unit, a cryogenic freezer, 8 exp columns, 8 sample</td>
<td>(1) p. 97</td>
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<td></td>
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<td></td>
<td>Test Project '75</td>
<td>insertion slides</td>
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<td>A16</td>
<td>Carrot Tumor Growth Expt. Crown gall</td>
<td>Crown gall tumors</td>
<td>Kosmos 782 '75</td>
<td>Specially machined acrylic canisters, consisting of a stack of 3 closely</td>
<td>(6) p. 33</td>
</tr>
<tr>
<td></td>
<td>developed on carrot disks</td>
<td></td>
<td></td>
<td>fitted dishes, 2 machined anodized aluminum caps, filter pads with</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>12 air holes (pins in Final rept)</td>
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<td>A17</td>
<td>Carrot Tissue Culture</td>
<td>Cultured carrot totipotent cells</td>
<td>Kosmos 782 '75</td>
<td>Specially constructed canisters, plastic petri dishes, 2 anodized aluminum alloy and caps 12 air holes; 4 standoffs (picture in Final report)</td>
<td>(6) p. 71</td>
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<tr>
<td>A18</td>
<td>Cytological Studies of Mammalian Cell Cultures</td>
<td>Chinese hamster &amp; mouse cells</td>
<td>Cosmos 1129 '79</td>
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<td>(7) p. 9</td>
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<td>A19</td>
<td>Studies of Carrot Crown Gall Tumor</td>
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<td>Cosmos 1129 '79</td>
<td></td>
<td>(8) p. 57</td>
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<td></td>
<td>Culture Morphogenesis</td>
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<td>A20</td>
<td>Studies of Carrot Tissue Culture</td>
<td></td>
<td>Cosmos 1129 '79</td>
<td>Basal medium of salts, sucrose, vitamins NAA</td>
<td>(9) p. 57</td>
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<td>Morphogenesis</td>
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<td>A21</td>
<td>Efficiency of Separation of Rat pituitary cells</td>
<td>STS-8 '83</td>
<td></td>
<td>Blood kit, Cell Culture Flasks, Syringes, Medium, Type 1 experiment containers, See Hardware</td>
<td>(3) p. 145</td>
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<td>A22</td>
<td>Effects of low gravity on Mammalian Cell Polarization at the Ultrastruct. level</td>
<td>mammalian plasma cells</td>
<td>Spacelab D-1 '85</td>
<td></td>
<td>(4) p. 105</td>
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<td></td>
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<td></td>
<td>Section 2.1, 2.2, 2.3, 2.4, &amp; 3.</td>
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<td>A24</td>
<td>Rearrangement of Intermediate Filaments in Mammalian Cells in Culture</td>
<td>Several types of mammalian cells and tissues</td>
<td>Spacelab J (91)</td>
<td>Thermoelectric Incubator (TEI) See Hardware section 14</td>
<td>(14) p. 30</td>
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## 2. Oocyte/Embryo Development

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<tr>
<td></td>
<td>Embryogenesis - Ascaris eggs</td>
<td>Sputnik 6 '61</td>
<td>Cylinder of 8 specimen chambers, each divided into 3 compartments</td>
<td>(5) p. 31</td>
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<td>B2</td>
<td>Sea Urchin Egg Fertilization</td>
<td>Gemini 3 '65</td>
<td>separating sperm, ova and fixative solution</td>
<td>(1) p. 139</td>
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<td></td>
<td>and Development</td>
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<td>B3</td>
<td>Embryology development studies</td>
<td>Gemini 8 '66</td>
<td>4 specially developed acrylic chambers, temp held at 4 C then raised to</td>
<td>(9) p. 193</td>
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<td></td>
<td>- 20 Rana eggs</td>
<td>Gemini 12 '66</td>
<td>21 C at orbit. Eggs then injected with glutaraldehyde fixative at</td>
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<td></td>
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<td>various stages.</td>
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<td>B4</td>
<td>Effect of Weightlessness</td>
<td>Biosat. I '66</td>
<td>16 acrylic modules divided into 2 chambers, a 10 ml egg chamber, and</td>
<td>(1) p. 137</td>
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<td></td>
<td>on the Dividing Eggs - (B. frog)</td>
<td>Biosat. II '67</td>
<td>a 4 ml-fixative chamber, a coolant line around the pkg to maintain it</td>
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<td>- 120 Rana eggs</td>
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<td>at 42.5 oF, thermistors</td>
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<td>B5</td>
<td>Amphib. development - differentiation and function of the gravity</td>
<td>Soyuz-9 '70</td>
<td>Placed eggs from Rana temporaria and Xenopus</td>
<td>(5) p. 27</td>
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<tr>
<td></td>
<td>sensing system in early embryos</td>
<td>Soyuz 17 '75</td>
<td>laevics in containers. At various stages of development, glutaraldehyde</td>
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<td>exposed to microgravity</td>
<td>Soyuz 26 '77</td>
<td>was injected manually.</td>
<td>(10) p. 62</td>
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<td></td>
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<td>Soyuz 36 '80</td>
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<td>Soyuz 39 '81</td>
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<td>Soyuz 40 '81</td>
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<tr>
<td>B6</td>
<td>BIOSTACK I, II</td>
<td>Apollo 16, 17 '72</td>
<td>Hermetically sealed aluminum container, containing series of select</td>
<td>(1) p. 128</td>
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<tr>
<td></td>
<td>To study biological effects of</td>
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<td>biologic mat'ls each sandwiched</td>
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<td></td>
<td>individual heavy nuclei with</td>
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<td>biologic mat'ls each sandwiched</td>
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<td>high energy loss (HZE) - Brine</td>
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<td>biologic mat'ls each sandwiched</td>
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<td>Shrimp eggs</td>
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<td>biologic mat'ls each sandwiched</td>
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<td>B7</td>
<td>BIOSTACK II</td>
<td>Apollo 17 '72</td>
<td>thermistors</td>
<td>(1) p. 129</td>
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<tr>
<td></td>
<td>- Grasshopper eggs</td>
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<td></td>
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<tr>
<td>B8</td>
<td>BIOSTACK II</td>
<td>Apollo 17 '72</td>
<td></td>
<td>(1) p. 130</td>
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<tr>
<td></td>
<td>- Flour beetle eggs</td>
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<td>B9</td>
<td>Development of Fundulus</td>
<td>Skylab 3 '73</td>
<td>No special equipment (not intended to be an experiment)</td>
<td>(9) p. 193</td>
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<td>B10</td>
<td>Fundulus dev. - 500 embryos</td>
<td>Apollo-Soyuz ('75)</td>
<td>Machined aluminum, 2 chamber, cuboid case with 5 polyethylene bags (Picture in Final rept)</td>
<td>(9) p. 194</td>
</tr>
<tr>
<td>B11</td>
<td>5 development stages of Fundulus studies (500 embryos)</td>
<td>Kosmos 782 ('75)</td>
<td>Machined aluminum, 2 chamber, cuboid case with 5 polyethylene bags (Picture in Final rept)</td>
<td>(6) p. 179</td>
</tr>
<tr>
<td>B12</td>
<td>BIOSTACK III</td>
<td>Apollo-Soyuz</td>
<td>PVA, 2 cylindrical aluminum containers, K2 nuclear emulsion plates</td>
<td>(1) p. 131</td>
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<tr>
<td></td>
<td>To study the influence of HZE particles on development, morphogenesis, and histology</td>
<td>Test Project ('75)</td>
<td>Tainers, K2 nuclear emulsion plates</td>
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<tr>
<td></td>
<td>- Brine S., flour b. &amp; grass-H. eggs</td>
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<tr>
<td>B13</td>
<td>Killifish Hatching and Orientation</td>
<td>Apollo-Soyuz</td>
<td>Transport control pkg, experimental pkg, rotating striped drum, photog. equipment</td>
<td>(1) p. 132</td>
</tr>
<tr>
<td>B14</td>
<td>Study of Embryogenesis in Jap. Quail - 60 Coturnix eggs</td>
<td>Cosmos 1129 ('79)</td>
<td>Inclibrator</td>
<td>(9) p. 196; (7) p. 324</td>
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<tr>
<td>B15</td>
<td>Embryogenesis &amp; Organogenesis in spaceflight - Stick insect Carausius</td>
<td>Spacelab D-1 ('85)</td>
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<td>(4) p. 107</td>
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<td>B16</td>
<td>Fertilization &amp; Development in Spacelab - M&amp;F gametes</td>
<td>Spacelab D-1 ('85)</td>
<td>Special containers with 6 compartments were fabricated for individual storage of eggs, sperm</td>
<td>(10) p. 64</td>
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<tr>
<td></td>
<td>African Clawed frog</td>
<td></td>
<td>glutaraldehyde fixative, Ringers solution, distilled water, and an anti-sperm sera to label the spot of sperm penetration. Temp. maintained in chambers at 11°C until orbit.</td>
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<td>1 to 2 hours after reaching orbit, chambers placed in incubator at 22°C. A microprocessor on each container then activated plungers in each chamber mixing sperm and eggs and subsequently flooded them with dilute Ringers solution. Fixation of all specimens occurred about 8 to 9 hours after fertilization (at gastrula stage).</td>
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<td>B17</td>
<td>Embryonic Development of the Vertebrate Gravity Receptors -</td>
<td>Spacelab D-1 ('85)</td>
<td>Fertilized eggs stored at 10 C in incubator, located in a Space Shuttle middeck locker.</td>
<td>(10) p. 63</td>
</tr>
<tr>
<td></td>
<td>Clawed frog eggs</td>
<td></td>
<td>7 hours after launch, the developmental rate was accelerated by raising temp. to 20 C with in incubator in spacetlab.</td>
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<td><strong>FUTURE EXPERIMENT:</strong></td>
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<tr>
<td>B18</td>
<td>Fertilization and development in Microgravity</td>
<td>Spacelab-J ('91)</td>
<td>Designed to fly 4 adult females. Spacelab crew to induce ovulation and subsequent fertilization during the flight. Damp foam-lined box through which 100 cc/min of air will be circulated. Sperm suspension will also be prepared. Adult Frog Container (AFC) loaded into a special incubator. The Frog Environmental Unit (see fig.) located in the spacetlab. AFC will be transferred to the General Purpose Work Station (a glovebox containing chemical and biological materials - see fig.). In the GPWS, the frogs will be injected with chorionic gonadotropin to induce ovulation. Chambers filled with dilute Ringers solutions will hold eggs covered with sperm suspension. Incubation temp. will be 21 C. See Souza article for details.</td>
<td>(10) p. 65</td>
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3. Microorganisms

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<tr>
<td>C1</td>
<td>Radiobiology Expts.</td>
<td>Discoverer</td>
<td>Caramelized glucose, glass ampules</td>
<td>(1) p. 157</td>
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<td></td>
<td>II Clostridia Spore labilization: XVII, XVIII ('60)</td>
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<td>refrig. units for the ground, thermistors</td>
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<td>A Biological System to quantitate radiation</td>
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<td>track plates, chem. dosimeters,</td>
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<td>needle sets</td>
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<td>C2</td>
<td>Correlate traversal of primary cosmic rays with an increase in mutation in a population of cells lying along the track path - Neurospora crassa</td>
<td>Discoverer XVIII ('60)</td>
<td>Biological track plate, millipore filters, photog. emulsion on a 2&quot;x2&quot; sheet of glass, neutron sensitive film, Anscor 552 film, antimony foil, alanine and albumin</td>
<td>(1) p. 159</td>
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<tr>
<td>C3</td>
<td>Experiments with Photo-Synthetic Organisms - Algae</td>
<td>Discoverer XVII ('60)</td>
<td>Glass vials, chem. dosimeters, modified Evelyn photoelectric colorimeter, alanine, albumin, silver-activated phosphate glass rods, Anscor 522 Film, neutron sensitive film, antimony foil, nuclear track plates</td>
<td>(1) p. 166</td>
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<td>C4</td>
<td>Genetic Experiments on NERV - Neurospora crassa</td>
<td>NERV 1 ('61)</td>
<td>Experiment capsules</td>
<td>(1) p. 158</td>
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<td>C5</td>
<td>Survival - Actinomycetes</td>
<td>Sputnik 6 ('61)</td>
<td></td>
<td>(5) p. 35</td>
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<td>C6</td>
<td>Survival - Actinomycetes</td>
<td>Sputnik 7 ('61)</td>
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<td>(5) p. 35</td>
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<td>C7</td>
<td>Survival - Yeast</td>
<td>Vostok 2 ('61)</td>
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<td>(5) p. 31</td>
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<td>C8</td>
<td>Survival - Yeast</td>
<td>Voskhod 1 ('64)</td>
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<td>(5) p. 31</td>
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<td>C9</td>
<td>Mutational and Physiological Responses of Habrobracon - Parasitic wasp, brine shrimp cysts, Saccharomyces cerevisiae</td>
<td>Biosat II ('67)</td>
<td>Habrobracon flight containers, 85Sr source, LIF powder, glass rod dosimeters</td>
<td>(1) p. 135</td>
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<td>C10</td>
<td>Mutagenic effectiveness of Known Doses of Radiation in Combination with Zero-G on Neurospora crassa</td>
<td>Biosat II ('67)</td>
<td>Millipore filters, LIF disk dosimeter, porous retaining rings, module of sample holders, 85Sr source, thermistor</td>
<td>(1) p. 160</td>
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3. Microorganisms (Continued)

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<tr>
<td>C11</td>
<td>Effects of Weightlessness on the Nutrition and Growth of Pelomyxa carolinensis</td>
<td>Biosat II ('67)</td>
<td>Expt pkg with 24 chambers each divided into 3 5-ml compartments containing amoeba or fixitive. The chambers were mounted on magnesium plates. 4 of the chambers contained thermistors.</td>
<td>(1) p. 95</td>
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<tr>
<td>C12</td>
<td>Nuclear and Cellular Division in Pelomyxa carolinensis during Weightlessness (Amoeba)</td>
<td>Biosat II ('67)</td>
<td>same as (7)</td>
<td>(1) p. 103</td>
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<tr>
<td>C13</td>
<td>Radiation Exposures During Flight - Variety Animal &amp; Plant microorganisms</td>
<td>Biosat II ('67)</td>
<td>Capsule, experiment pkg, nuclear emulsion pkg, back-scatter shield, heat shield, source holder, 85Sr source, LIF powder dosimeters, CaF2 dosimeters</td>
<td>(1) p. 119</td>
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<tr>
<td>C14</td>
<td>Survival - Yeast</td>
<td>Kosmos 368 ('70)</td>
<td></td>
<td>(5) p. 31</td>
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<td>C15</td>
<td>BIOSTACK II</td>
<td>Apollo 17 ('72)</td>
<td>Hermetically sealed aluminum container</td>
<td>(1) p. 167</td>
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<td>To study biological effects of individual heavy nuclei with high energy loss (HZE) protozoan cysts</td>
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<td>C16</td>
<td>Microbial Response to Space Environment - Various</td>
<td>Apollo 16 ('72)</td>
<td>See (72)</td>
<td>(1) p. 172</td>
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<td>C17</td>
<td>Symbiotic Growth of Chlorella and Keilr in Micro-Gravity (Algae &amp; Yeast)</td>
<td>STS 51-G ('85)</td>
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<td>(4) p. 96</td>
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<td>18</td>
<td>Contraction Behaviour and Protopod Streaming in the Slime Mould Physarum Polycephalum</td>
<td>Spacelab D-1 ('85)</td>
<td>Designed light microscope that could be mounted in the Biorack glovebox. The microscope contained 16-mm film cassettes to register the shuttle streaming and permitted the integration of the photo-diode in one ocular for registration of the radial contractions of a strand. The analogue signals of the diode were digitized by means of digitizing amplifiers. The amplifier electronics were especially developed for this Spacelab experiment.</td>
<td>(12) p. 55</td>
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<td>19</td>
<td>The Paramecium Experiment</td>
<td>Spacelab D-1 ('85)</td>
<td>Cells cultivated in a straw medium bacterised with Aerobacter aerogenes. 10 day, postautogamous cells were isolated by cloning. The eight sister cells obtained after 3 divisions were isolated and each cell placed in a small plastic bag with 0.65 ml of culture medium. Each bag included 2 small glass ampulæ filled with 30 μl of a fixative (glutaraldehyde 35% in cacodylate buffer 0.2 M) according to the techniques developed for the Cytos experiments. After welding the bags and checking cell viability, the bags were placed in culture boxes. Each box included 4 small metallic spindles, which, when rotated by a crew member, caused the glass ampulæ to break. Fixative then spread out so that the whole culture was fixed within 1 or 2 minutes. Culture boxes</td>
<td>(12) p. 70</td>
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ATTACHMENT C

CELL RESEARCH HARDWARE/FACILITIES
(FLOWN/PLANNED/EXISTING)

1. Cell Research Flight Hardware
2. Groundbased NASA Facilities
1. Cell Research Flight Hardware

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<td>HARDWARE</td>
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<td>3</td>
<td>1</td>
<td>Woodlawn Wanderer 9</td>
<td>Maintained ambient temp. of 10 C and 35 C.</td>
<td>Skylab</td>
<td>(2) p. 222</td>
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<td>4</td>
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<td>Sealed to provide 1 atm pressure. Internally, the</td>
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<td>5</td>
<td></td>
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<td>package is separated into a camera-microscope</td>
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<td>6</td>
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<td>section and a separately sealed growth curve</td>
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<td>7</td>
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<td>experiment section. See Fig.</td>
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<td>9</td>
<td>2.1</td>
<td>Blood-Kit</td>
<td>Consisted of a bag of Nomex containing lithium-heparin coated syringes, tourniquets, cotton-wool</td>
<td>Biorack on</td>
<td>(12) p. 90</td>
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<td>Spacelab D-1</td>
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<td>11</td>
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<td>balls, surgical tape, wiping towels.</td>
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<td>13</td>
<td>2.2</td>
<td>Cell Culture flasks</td>
<td>Made of teflon/glass fiber consisted of cylindrical chambers (10 ml) sealed by a mobile piston, and</td>
<td>Biorack on</td>
<td>(12) p. 90</td>
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<td>14</td>
<td></td>
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<td>were designed and developed in our laboratory.</td>
<td>Spacelab D-1</td>
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<td>15</td>
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<td>such flasks fit into Type 1 standard Biorack expt container.</td>
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<td>16</td>
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<td>Fresh blood samples and other reagents were injected (using 1 ml tuberculin syringes) into the flasks through a silicon rubber septum fitted in the piston.</td>
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<tr>
<td>18</td>
<td>2.3</td>
<td>Syringes</td>
<td>Used for injecting con A, 3H-thymidine, and glutaraldehyde-modified to fit into a Biorack container.</td>
<td>Biorack on</td>
<td>(12) p. 90</td>
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<td>Spacelab D-1</td>
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<td>22</td>
<td>2.4</td>
<td>Medium</td>
<td>The medium (RPMI 1640, Gibco) was supplemented with 20% heat-inactivated human serum of the same blood group as the donor's, and contained 1000 I.U. heparin, 50 mg/ml gentamycin, 40 mM Hepesbuffer and 5 mM sodium bicarbonate. The last 2 components permit culture growth in the absence of a controlled CO2 atmosphere in sealed flasks. Cells were stimulated by injecting con A at 50 mg/ml.</td>
<td>Biorack on</td>
<td>(12) p. 91</td>
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<td>3.4</td>
<td>HARDWARE</td>
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<td>35</td>
<td>3.5</td>
<td>3. Type I experiment A flight container (FM), a ground control container</td>
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<tr>
<td>36</td>
<td>3.6</td>
<td>containers (TM) and a spare one. Each contained 4 sets of 2</td>
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<td>37</td>
<td>3.7</td>
<td>bags each with 1.4 ml of cell suspension (200,000 cells/ml) and either no</td>
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<td>38</td>
<td>3.8</td>
<td>vials, 2 vials containing fixative, and 2 vials containing fixative, and</td>
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<td>39</td>
<td>3.9</td>
<td>bags were sealed before being placed in the experiment containers. In flight, crew members broke the</td>
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<td>40</td>
<td>4.0</td>
<td>glass ampoules at scheduled times to release the fixative or labelled solution.</td>
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<td>41</td>
<td>4.1</td>
<td>apparatus for providing industrial users with a convenient, low-cost, modular experiment system for fundamental research in biology, aerospace engineering, and applied processing or product development experiments in general liquid chemistry, crystal growth, fluid mechanics, thermodynamics, and cell culturing of biological materials and living organisms. This general-use, adaptable facility can be configured to manipulate a wide variety of experiments including gaseous, liquid, or solid samples, and expose samples to vacuum conditions, and heat and cool samples. A number of specialized subsystems are planned for the FEA, including low-high-temperature furnaces, custom-designed heaters, special sample containers and a specimen centrifuge. These modules will allow FEA hardware and operations to be customized to support a wide range of experiment requirements.</td>
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<td>68</td>
<td>5. Refrigerator freezer</td>
<td>An active unit with a temperature range from -22 to +10°C. It can be used to cool blood, body fluids, and cell samples as well as solutions and fluids intended for injection. It also may be used to house small animals, to incubate amphibian zygotes and to stow animal food supplies. It is designed to accept experiment racks, shelves and containers for a variety of purposes. 2 units are available: 1 designed for the orbiter middeck and 1 for Spacelab.</td>
<td>(13) p. 4-35</td>
<td></td>
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<td>70</td>
<td>6. Phase partitioning experiment apparatus (PPE)</td>
<td>Measures the spontaneous demixing of liquid-liquid, aqueous polymer 2-phase systems. 2 phase separation is universally used to separate biological cells and proteins. PPE permits the study of altering volume ratios, viscosity, interfacial tension, interfacial bulk phase potential, phase composition on the kinetics of demixing and the effects of chamber geometry, materials and wall coatings of the foregoing parameters. The PPE is configured to study natural coalescence and surface tension, 2 methods of phase separation. It also allows variations in interfacial tension, phase volume ratios, phase system composition and added particles. Up to 24 separate cavities can be filled with small quantities of 2 different polymers in simple water/salt solutions. The apparatus is shaken and photographed to record phase separation.</td>
<td>(13) p. 4-37</td>
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<tr>
<td>95</td>
<td>7. Refrigerator/Incubator</td>
<td>An active unit with a temperature range from 0 to +40°C. The temperature is set using a front-mounted variable potentiometer. Switching between the refrigeration and incubation modes occurs automatically</td>
<td>(13) p. 4-37</td>
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1. Cell Research Flight Hardware (Continued)
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<td>100</td>
<td></td>
<td>8 Refrigerator/incubator</td>
<td>Provides an easily integrated, temperature-controlled</td>
<td></td>
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<td>101</td>
<td></td>
<td>module (RIM)</td>
<td>storage area for experiment samples, such as living</td>
<td></td>
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<td>102</td>
<td></td>
<td></td>
<td>cells, organisms and materials which must be maintained</td>
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<td>103</td>
<td></td>
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<td>at specific temperatures in preparation for or after processing.</td>
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<td>104</td>
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<td>This RIM can be controlled to 1 degree intervals between 4 and 37.5 C.</td>
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<td>107</td>
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<td>9 Tissue Culture incubator</td>
<td>Capable of maintaining 37 C (+/- 0.5 C). It can house 4 15-ml cultures. The culture chambers are made of teflon and glass and are equipped with a septum permitting the addition of material in flight via syringes also stored in the incubator. The syringes may be either modified 5-ml or standard syringes. The cultures are designed to be liquid only. Volume expansion of the culture vessels is achieved by a teflon-sleeved piston arrangement in which the septum is housed. The incubator can be mounted in a standard 19-inch electronics (or experiment) rack or be carried alone in a battery mode removed from the rack.</td>
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<td>109</td>
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<td>10 Cell Culture Kit</td>
<td>A set of apparatuses, main chamber units, medium containers, waste collectors, and glutaraldehyde applicators, for mammalian cell culture experiments. The main chamber unit has 2 rooms separated by a semipermeable membrane with 2 sets of septa for medium exchanges or chemical treatments free from contamination. The oxygen concentration in the medium can be spontaneously maintained from the atmosphere. The temperature and humidity are controlled by the incubator (TEIHT). Plant culture chambers are also included in kit. See fig.</td>
<td>Planned for SL-J mission --Japanese</td>
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<td>122</td>
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<td>11 Type I container</td>
<td>With the microchambers fitted with agar-coated red glass windows and a microscope. (for slime mold Physarum Polycephalum experiment)</td>
<td>Spacelab D-1 (12) p. 59</td>
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<td>139</td>
<td></td>
<td>12 Culture box</td>
<td>(see description with pictures)</td>
<td>Spacelab D-1 (12) p. 70-71</td>
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<td>Free Flow Electrophoresis</td>
<td>A continuous flow type electrophoresis equipment developed for the charged material separations under conditions of microgravity. The separation chamber has been modified to be much thicker compared to ground use equipment, because there are no restrictions of thermal convection or sedimentation phenomena. The system is equipped with a dedicated microprocessor for operations and environmental controls as well as data processing. The sample separation can be monitored by a real-time, multichannel detector directly coupled with the electrophoresis chamber. The equipment adopts a wide variety of specimens for separation from homogeneous solutions to charged suspensions, such as cultured cells or organella.</td>
<td>Spacelab J-1 (14) p. 26 (pics)</td>
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<td>142</td>
<td></td>
<td>Unit (FFEU)</td>
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<td>143</td>
<td>1.3</td>
<td>Thermoelectric Incubator</td>
<td>Developed for Spacelab experiments as a fundamental tool for life sciences. Both temperature and humidity are regulated at preset values. The two sets of incubators provide different experimental environments, in which cell culture and calcium metabolism experiments are performed using TEI-HT (37°C). The enzyme crystallization and radiation biology experiments employ TEI-LT (20°C)</td>
<td>Spacelab J-1 (14) p. 30 (pics)</td>
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<tr>
<td>NAME</td>
<td>DESCRIPTION</td>
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<td>Bioprocessing/Cell</td>
<td>Used for the culturing of cells for separation in ground-based and Space Shuttle flight experiments, evaluation of attachment of cells to substrata in microgravity, development of experiments to evaluate the effects of space environment on cells, development of a bioreactor capable of operating in a microgravity environment, and preparation of cells for bioreactor studies. SUPPORTS: Cell biology and tissue culture research, cell production, and evaluation in support of Space Shuttle and Space Station experiments, design and construction of a space prototype bioreactor.</td>
<td>1979 (15)</td>
<td>p.6.2-5</td>
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<td>Biology Research Laboratory (CBRL)</td>
<td>Digitizes cell images for the analysis of biomedically important changes such as gross cell damage, chromosome breaks, or changes in cell age and type. Fluorescent tagged cells may be identified, sorted, and recultured for further analysis as required (for example, in cell cycle analyses and the study of anomalies in the immune mechanism or in red blood cell production). SUPPORTS: Electro-optical digitization of cell images and fluorescent-activated flow cytometry.</td>
<td>1973</td>
<td>(15) p. 6.2-9</td>
<td></td>
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LIST OF REFERENCES FOR ATTACHMENT B

References for Cell Research Experiments (Flown/Planned)


References for Cell Culture/Embryology Flight Hardware


Reference for Ground-Based NASA Cell Culture Facilities


SUGGESTED READINGS


## Report Documentation Page

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<th>NASA CP-10034</th>
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<td>4. Title and Subtitle</td>
<td>Cells in Space</td>
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<td>5. Report Date</td>
<td>August 1989</td>
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<td>6. Performing Organization Code</td>
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<td>7. Author(s)</td>
<td>Jean D. Sibonga and Richard C. Mains (Mains Associates, Berkeley, CA); Thomas N. Fast (U. of Santa Clara, Santa Clara, CA); Paul X. Callahan and Charles M. Winget, editors</td>
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<td>9. Performing Organization Name and Address</td>
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<td>10. Work Unit No.</td>
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<td>12. Sponsoring Agency Name and Address</td>
<td>National Aeronautics and Space Administration, Washington, DC 20546-0001</td>
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<td>13. Type of Report and Period Covered</td>
<td>Conference Publication</td>
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<tr>
<td>15. Supplementary Notes</td>
<td>Point of Contact: Paul X. Callahan, Ames Research Center, MS 240-A3, Moffett Field, CA 94035 (415) 694-6046 or FTS 464-6046</td>
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<td>16. Abstract</td>
<td>A conference, co-organized by the Space Life Sciences Payloads Office and the External Relations Office at Ames Research Center, was held from October 31 through November 4, 1988, at San Juan Bautista, California. Discussions and presentations at this conference addressed three aspects of cell research in space: (i) the suitability of the cell as a subject in microgravity experiments, (ii) the requirements for generic flight hardware to support cell research, and (iii) the potential for collaboration between academia, industry, and government to develop these studies in space. This publication gives synopses of the presentations and of follow-on discussions at the conference and contains papers from which the presentations were based. An Executive Summary outlines the recommendations and conclusions generated at the conference.</td>
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