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DESIGN, DEVELOPMENT, AND VERIFICATION OF LIFE SCIENCES EXPERIMENTS

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ABSTRACT

A prime objective of the Life Sciences Flight Experiments Program is to conduct a continuing and coordinated program of biomedical research in space which supports the goals of NASA's Life Sciences. To accomplish this objective NASA has developed an effective NASA-industry-academic team to design, develop, test, and operate Life Sciences payloads for Space Shuttle flights. Ames Research Center, the prime NASA center responsible for development of nonhuman life sciences experiments, works closely with Lyndon B. Johnson Space Center and NASA Headquarters' Life Sciences Division in the development of scientifically balanced payloads. Johnson Space Center has responsibility for human experiment development, pre-level IV payload assembly and verification, program management and mission management of Life Sciences Missions.

Life Sciences experiments designated for flight aboard Spacelabs 1, 2, and 3 are in final stages of development and verification. Those slated for flight aboard the first Spacelab entirely dedicated to Life Sciences experiments, LS-1, are undergoing a final NASA selection process.

Ames and JSC facilities preparations and GSE required to support training and individual experiment, rack-level and dedicated Spacelab verification are on schedule. Reflyable life sciences laboratory equipment (LSLE) required for the early missions is being developed and certified for flight and, across the program, challenges resulting from pressing scientific questions, resource limitations, competition for skilled personnel, and situations resulting from a lengthy time span since the Apollo and Skylab flights are being addressed in a variety of ways.

PROGRAM BACKGROUND

Goals. Goals which have been established for the overall NASA Life Sciences Program within which resides the Space Shuttle Life Sciences Flight Experiments Program (LSFEP) include the following:

- Ensure human health, safety, and effective performance in space
- Utilize the space environment to further knowledge in medicine and biology
- Utilize space technology and the space environment for application to terrestrial medicine and biological problems
- Understand the origin and distribution of life in the universe

The first goal, and to a lesser extent the second, has had the greatest influence upon development of the LSFEP and its experiments to date. Both short and long term physiological changes have been observed in crewmen during and after space flight that must be better understood in the Space Shuttle era and as flight durations increase. An example of a troublesome physiological response whose mechanism is not completely understood is space motion sickness which occurs frequently upon onset of the weightless environment. Crew comfort and performance can suffer for a matter of days depending upon the severity of the response seriously impacting the success of a seven or ten day Shuttle mission. A variety of other hormonal and chemical changes are also triggered soon after launch and are accompanied by fluid redistribution within the body, progressive cardiovascular deconditioning and muscle atrophy.

Longer term exposures to zero gravity during Soviet and U.S. flights have revealed changes...
of sufficient magnitude and complexity to warrant detailed studies of endocrinologic and metabolic changes during and postflight.

Significant changes in fluid and electrolyte balance; regulation of calcium metabolism; adrenal function and carbohydrate, fat, and protein utilization have been observed. Observed changes in red blood cell mass and bone demineralization are not completely understood and have implications for long missions.

Studies of these responses to the stressors encountered in space will provide additional insights into the mechanisms involved. This will benefit man on earth as well as crewmen and will assist in the development of preventive or countermeasures.

As these mechanisms are studied and as the unique weightless environment of space is used directly for fundamental medical and biological studies, the second and third goals are addressed. All living systems are influenced by gravity to some degree and study in space of gravitational effects at the subcellular, cellular, organ, and whole-body levels will add to an important body of knowledge. This knowledge can in turn lead to an understanding of certain practical problems of human physiology and of the ecological systems necessary for long-term space flight and perhaps for man's future on earth.

The fourth and last goal deals with a subject of increasing interest, the possibility of extraterrestrial life, particularly intelligent extraterrestrial life, in the universe. Although this last goal has had little impact upon the LSFEP to date, questions concerning the origin and distribution of life in the universe are intriguing and may have future impact upon the flight program.

Objective. The objective of the Flight Experiments Program is to provide a life sciences laboratory in space where scientists can have their experiments performed at relatively low cost. Spacelabs fully dedicated to life sciences experiments are scheduled to begin flying in 1984 at 18-month intervals. Each dedicated Spacelab will accommodate approximately 20 life sciences experiments which will be designed to complement each other to the extent feasible, achieve the mission science objective, and otherwise maximize utilization of the flight opportunity. The frequency of dedicated flights can be increased to one every 12 months if additional program funding is provided and flight opportunities exist. Other opportunities to conduct life sciences experiments are provided by interdisciplinary Spacelab missions and by the carry-on experiment concept. Spacelab flights shared by multiple scientific disciplines are providing opportunities to fly minilabs, three to six experiments arranged in double or single Spacelab racks, as illustrated by Figure 1, with the first such experiments due to fly in Spacelab 1. Other minilab flights scheduled to follow Spacelab 1 which is slated for mid-1983 launch are Spacelab 2, scheduled for a late 1983 launch, and Spacelab 3, scheduled for mid-1984 launch.

Organization. NASA has devised a 3-level organization as illustrated by Figure 2 to manage the LSFEP and to take advantage of special field center skills and expertise. Overall program responsibility resides in the office of Program Director at NASA Headquarters and is referred to as "Level 1." The LSFEP Director reports to the Director, Life Sciences Division, Office of Space Sciences, who in turn reports to the Associate Administrator for Space Science.

A Program Manager has been designated at Johnson Space Center (JSC) responsible for management of the budget, schedule, program cost, and implementation at the three participating field centers and coordination of science, technology, and operations. This level of management is referred to as "Level 2."

Project Divisions at JSC and Ames Research Center (ARC) have been assigned responsibilities for the design, development, assembly, and verification of experiments and supporting systems; for the conduct of scientific investigations; for the support of and interface with principal investigators and for assisting in payload integration. JSC has lead center responsibility for all human experiments and ARC for nonhuman experiments. These Project Divisions and a Project Division at Kennedy Space Center (KSC) are designated as "Level 3" and interface with Level 2 in a project sense. The KSC Level 3 activity supports life sciences payload integration and preflight, in-flight, and post-flight payload operations at KSC including designated experiment control studies to be conducted at KSC.

Support Contractor. NASA has awarded a prime contract to Management and Technical Services Company (MATSCO), a subsidiary of General Electric Company, to provide scientific and technical support for all program phases. Government facilities and personnel are used in the integration, test and checkout, mission preparation, mission monitoring, and operations, and more, but substantial program elements are contractor manned and managed. Functions performed by MATSCO at ARC, JSC, KSC, and Headquarters include the following:

- Level of effort support of program management, science management and operations, hardware and software development, systems verification and test, payload integration, and mission planning operations.
Acquisition of ground support equipment, re-flyable life sciences laboratory equipment, and selected experiment equipment as directed by NASA.

FLIGHT OPPORTUNITY PROCESS

Announcement of Opportunity (AO). NASA's techniques for notifying scientists that a flight opportunity exists include distribution of an Announcement of Opportunity (AO). The distribution is widespread, international in scope, and includes universities, research groups and individuals. An AO prepared by NASA and distributed in 1978 was designed to provide the broadest possible opportunity for life scientists to conduct space biomedical research in the Space Shuttle's Spacelab. Researchers were invited to submit proposals for experiments which would address one or more of the following criteria:

a. Investigate physiological performance and biomedical changes observed in space
b. Identify and investigate significant biological phenomena which may occur during and/or after exposure to the space environment.
c. Test and demonstrate under operational conditions equipment and procedures needed by the NASA Life Sciences Program to meet its overall goals.

Approximately 400 proposals were received by NASA which then performed detailed science, engineering, operational and mission analyses of the proposed investigations.

Proposal Review and Experiment Selection. The first proposal reviews were conducted by peer review panels commissioned to establish scientific merit under the auspices of the American Institute of Biological Sciences (AIBS). After 13 disciplinary AIBS panels scored proposals on science merit, NASA panels met to consider technical aspects. Technical and scientific figures of merit were compiled and each proposal was assigned one of the selection categories shown by Table 1.

| Category I: | Well conceived and scientifically and technically sound investigations pertinent to the goals of the program and the Announcement's objectives and offered by a competent investigator from an institution capable of supplying the necessary support to ensure that any essential flight hardware or other support can be delivered on time and that data can be properly reduced, analyzed, interpreted, and published in a reasonable time. Investigations in Category I are recommended for acceptance.

| Category II: | Well conceived and scientifically or technically sound investigations which are recommended for acceptance, but at a lower priority than Category I.

| Category III: | Scientifically or technically sound investigations which require further development. Category III investigations may be funded for development and may be reconsidered at a later time for the same or other opportunities.

| Category IV: | Proposed investigations which are recommended for rejection for the particular opportunity under consideration, whatever the reason.

Table I. NASA Life Sciences Shuttle Experiment Categories

During the science and technical evaluations data on potential common use, between experiments, of laboratory equipment; mass properties; consumable resource requirements; crew time; experiment volume and configuration; expected costs; and other factors were recorded for use during the synthesizing of payloads.

Payload Synthesis. Payload synthesis is the process of selecting and combining experiments to meet or best satisfy imposed conditions and constraints. Such conditions and constraints might include goals to maximize science return based on categorization and consistent with mission science or established flight objectives; to maximize common use of equipment and experiment data; and provide optimum use of Spacelab resources including crewtime, allocated volume, mass, power, and other consumables.

Payload synthesis is an iterative and repetitive process as conditions, constraints, goals, and experiments which are expected to be ready for flight change as the effects of changing various factors are studied by scientists and managers. It was soon obvious that payloads addressing NASA's goals could be developed which were scientifically well conceived, satisfied Shuttle constraints, and were within budget guidelines. An outcome of NASA's experiment evaluation and payload synthesis activities was ultimately the selection of about 90 experiments to be further developed and studied during an experiment definition phase.

Experiment Definition Phase. NASA awarded definition phase contracts to about 90 of the original 400 investigators to obtain more detailed requirements for experiment development and to investigate the combining of selected experiments.
At the beginning of the definition phase engineers and scientists at the two NASA field centers formed teams which are assisting in development and analysis of experiment information. Documentation and in-depth knowledge of both experiment and mission factors developed during the definition phase will play key roles in final experiment selection for the first fully dedicated life sciences Spacelab mission, LS-1.

About 20 to 30 of the 90 experiments selected for definition phase studies are expected to fly aboard LS-1. Of the remaining 60 to 70, some will probably be afforded flight opportunities on interdisciplinary Spacelab missions similar to the Spacelab 1, 2, and 3 missions.

Early Flight Opportunities. Life Sciences experiments were selected for Spacelab 1 prior to NASA's release of the A.O. when the flight opportunity developed and subsequent interdisciplinary missions will afford additional flight opportunities for individual experiments and for groupings of experiments in flight racks. The seven experiments, for example, which will fly aboard Spacelab 1 in a double rack will study plant mutation, human vestibular function, erythrokinesis, immune response and the Spacelab radiation environment. The next life sciences early flight opportunity occurs on Spacelab 2, principally an astrophysics mission, when two carry-on experiments dealing with plant growth and calcium metabolism will be flown.

Spacelab 3 will provide an opportunity to evaluate under flight conditions some of the laboratory equipment and instrumentation being developed by NASA for the program. The mission is principally a materials science flight but will include a 5-rack life sciences mini-laboratory equipped to verify and evaluate equipment to be flown on the first life sciences dedicated flight. Some of the Life Sciences Laboratory Equipment (LSLE) developed by NASA is illustrated by Figure 3.

Final LS-1 Experiment Development. Development contracts will be awarded to the 20-30 investigators whose experiments are selected as prime candidates for the LS-1 missions. Finalization of flight and control experiment designs; laboratory investigations; documentation preparation; and design, development, and testing of experiment hardware and software will be accomplished during this funded phase. A focusing of the full talents and energies of the NASA engineering and science teams will take place at this time. Teams composed of NASA personnel, contractors and principal investigators and their staffs will be directed towards providing the most scientifically meaningful, efficient, Spacelab-compatible payload possible.

Facilities and services will be supplied by NASA during experiment development and certification on an as-needed basis. NASA's excellent qualification test capabilities at its field centers will be available to avoid duplication of capabilities and the data system support which can be provided investigators is impressive. Activities which are supported by the Life Sciences Data System (LSDS) include experiment checkout; science verification; payload development, assembly and verification; mission simulation; flight crew experiment support training; mission support; and post mission data processing. To minimize redundancy a common mission simulation and mission support hardware and software design philosophy has been followed. This has provided both cost savings and a vigorous exercising of systems under simulated mission conditions.

The total LSDS capability is provided by elements located at the field centers and is configured to serve the needs of each program phase. During missions, for example, LSPS minicomputers will be situated in the JSC Payload Operations Control Center (POCC) to receive life sciences experiment data from the POCC systems, perform predetermined data checks, and transmit the data to the JSC Life Sciences Experiment Facility for real-time recording, display and analysis. Investigators and mission support personnel will monitor experiment data in real-time and near real-time during missions and will be able to graphically compare results with control and predicted data using the LSPS.

Access to the LSPS by the ARC and KSC field centers and by NASA Headquarters will be possible via telephone links. Experiment and database data can be accessed and transmitted between centers for experiment checkout, during missions and as required to support various activities. Suitable safeguards have been instituted to place appropriate limits on system access.

Experiments delivered to the NASA field centers by investigators will undergo experiment checkout, verification that the assembled experiments can be performed as intended, and will be used for payload procedures development and crew training. Experiment integration and payload readiness for integration with the Spacelab will be KSC's responsibility with support provided by life sciences team members. After payload integration, payload-to-Spacelab interfaces will be verified, the Spacelab will be installed in the Orbiter, Spacelab-to-Orbiter interfaces verified, and the Orbiter will be transported to the VAB for further preflight processing.

During the mission experiments will be performed by four payload specialists who will fly the mission in addition to the regular
Astronaut crew of four. Investigations will study human responses to the space environment, as well as animal and plant responses. At the present time scientific priorities, goals, and the merits of individual and groups of experiments are being weighed by NASA in preparation for final experiment selection. A tentative payload will be selected within the next few months and initial experiment development initiated.

EXPERIMENT TYPES

Experiments selected for LS-1 can be expected to be grouped within one of the following seven discipline categories which have superseded the original 13 experiment categories used at the time of the peer review committees.

VESTIBULAR/SPACE SICKNESS

These experiments will investigate the causes of and means to prevent or reduce disorientation, nausea, and vomiting which often accompany the onset of weightlessness. Manifestation of the symptoms usually reduces crew efficiency during the first two to four days of flight. Symptoms may compound other changes noted in past missions by inducing dehydration, reducing food consumption, and reducing crew activity.

Research to be addressed by this group of experiments include evaluation of vestibular/neurosensory adaptation and sensory conflict and fluid shift theories of space sickness.

CARDIOVASCULAR

These experiments will investigate cardiovascular changes occurring in-flight and immediately postflight. Prior space research has shown that humans subjected to the zero-gravity of space exhibit post-flight orthostatic instability and a decreased exercise tolerance. Skylab data revealed that deconditioning symptoms occurred in-flight during the first few days of exposure to weightlessness. Deconditioning increases the likelihood of cardiac anomalies during the accelerative stress of reentry to earth's atmosphere and during readaptation to the normal 1-G condition. Research topics addressed by this group of experiments include evaluation of spaceflight-induced alterations of cardiac physiology, regulation of cardiac function, impact of fluid distribution on orthostatic tolerance and cardiac function, and means of preventing "cardiovascular deconditioning."

CARDIOPULMONARY

This group of experiments will assess how cardiopulmonary function changes in space. A battery of respiratory tests will be used to measure a range of parameters dealing with pulmonic function in an effort to assess the effects of zero-G, fluid shifts, and the gaseous environment on ventilation blood flow, gas exchange, alveolar size, intrapleural pressures and mechanical stresses within the human lung. The effects of weightlessness on nitrogen elimination from the body is a potential area of investigation. Pre-breathing requirements before extravehicular activity from the Shuttle Orbiter must be established. Research areas may include, effects of gravity and null gravity on various pulmonary parameters, and lung capacity and ventilation/perfusion.

RENAL/ENDOCRINE

These experiments will examine the specific causes and consequences of the rapid cephalad fluid shift which accompanies the onset of weightlessness. All past manned space flights have found that with the onset of weightlessness blood migrates from the legs, and possibly the abdomen, into the chest, neck and head. This fluid shift may have implications for the vestibular disturbances which occur during the early phases of space flight and cardiovascular deconditioning. Research areas of relevance include fluid/electrolyte regulation in weightlessness, and endocrine control of cardiovascular and renal functions.

HEMATOLOGY

Previous space research has shown that space flight results in a loss of blood volume and changes in the red cell volume. There are also concerns that the immune mechanism may be altered in space. Therefore, research areas of relevance include regulation of blood volume control, changes in red blood cell and plasma volumes in space, and erythropoiesis in space.

BONE-MUSCLE

These experiments will investigate the causes of, and means to prevent or reduce, bone and muscle mass loss observed in weightlessness. The problems of bone and muscle mass loss are not of clinical concern on short duration missions; however, they may be of major consequence in long duration missions. Short duration missions like Spacelab may be used to predict the effects of longer missions, to make fundamental mechanism studies, and to develop appropriate countermeasures. Research topics of interest include mechanisms of muscle deconditioning and wasting, mechanisms involved in bone and muscle mass loss, and effects of space on protein metabolism.

GENERAL BIOLOGY

This grouping includes several disciplines originally considered by the peer review
committees. It incorporates such disciplines as developmental biology, cell biology, plant physiology and general physiology. Experiments in this group provide basic knowledge about some of the functions which may be affected by space, but which have not been identified as causing acute problems in humans who fly in space. Research topics of relevance include thermoregulation in space; development of embryos in space; gravity, illumination and vibration response by plants to space; and carbohydrate/lipid metabolism as affected by space flight.

SUMMARY

The Space Shuttle Program is providing an excellent opportunity for the United States to improve its understanding of man's response to the space environment. At a time of international uncertainty one thing is certain and that is that free men must fully understand and use space to the best of their ability. A new era of reusable space hardware has been introduced which promises to lower the cost of space operations and research in low earth orbit and to provide in conjunction with use of the Spacelab a level of technical sophistication approaching that typical of earth-bound laboratories. The Life Sciences Flight Experiments Program is taking full advantage of the opportunities afforded to study the effects of space flight on man and other organisms, to study basic questions in biology, and to apply new understandings of such phenomena to the safe and efficient use of space by man. Several early flight opportunities are being utilized by the Life Sciences Flight Experiments Program to study questions of interest and to verify and evaluate laboratory equipment slated for the first life sciences dedicated mission. Experiments conducted during the first dedicated mission will extend life sciences research conducted during the Apollo and Skylab Programs and will begin to address questions which pertain to full utilization of Space Shuttle opportunities and the needs of longer missions.

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