FUTURE DIRECTIONS FOR THE LIFE SCIENCES IN NASA

A Report of the:

Life Sciences Advisory Committee

of the

NASA Advisory Council

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PREFACE

Although the 20-year period since man's entry into space is brief in terms of the known history of man on this planet, it is nevertheless a considerable span of years for a scientific endeavor. During this span, the achievements have been extraordinary, from thoroughly reliable, repeated insertions of spacecraft into orbit and well-controlled, safe returns to Earth, through linkage of vehicles in space and several landings on and safe returns from the Moon, to comfortable and productive orbital flights of up to three months and successful analyses for evidence of biological activity on Mars. In all of this endeavor of spectacular engineering and science, the role of biomedical sciences has mainly and necessarily been concerned with the requirements for human safety. Not until the Skylab flights could a substantial effort be mounted to observe, with some precision, human performance and physiological/medical functions in the strange environment of space. Outlines became visible, but much substance remains to be filled in to clarify the picture. Now, as the requests for approval and support of experiments are beginning to come in for the Shuttle/Spacelab Program, we are at the threshold of a fine opportunity to learn more definitively how man's life functions and fundamental biological processes are affected by weightlessness and other special characteristics of space. Even though the flights presently planned are of short duration, the possibility exists to find significant leads for more specific life science studies in longer flights – which hopefully will be supportable and conducted in the later 1980's.

Biological and medical consultation has been available to NASA in various forms, usually *ad hoc*, since the early 1960's. Formal establishment of the Life Sciences Advisory Committee took place in 1971. Since then, the Committee has given the Director for Life Sciences and NASA administration a variety of recommendations on particular biomedical activities as needed at the time. Finally, about 18 months ago, the Committee decided to undertake an organized, extensive review of the Life Sciences Program. A series of meetings of the full Committee, and more recently of an editorial team, has produced the present document.

The Committee was aware of a concurrent study being conducted by a special committee chaired by Dr. Neal Bricker, sponsored by the Space Science Board, Assembly of Mathematical and Physical Sciences, National Research Council/National Academy of Sciences. Some exchange of information took place between that study group and this Committee through attendance of two members of this Committee for a short time at the Snowmass Workshop in August 1977, but the SSB/NAS Report has not yet been released as of the time of submission for publication of this Report.

The purposes of this study and accompanying Report, "Future Directions for the Life Sciences in NASA," are:

(1) to provide NASA management with a concise picture (as we see it) of the major elements of the Life Sciences program and problems,

(2) to indicate the special, singular nature of the biological/medical concerns and efforts within the engineering and physical science programs which make up the bulk of NASA's activities, and

(3) to provide a series of suggestions in recommendation form as a basis for attempting to handle more effectively the important responsibilities of Life Sciences.

This document, we believe, provides many practical items as points of reference for dialogue and discussion, directed toward clarifying the diverse roles of the Life Sciences Program in future NASA activities.

This Report is the final effort of most members of the current Life Sciences Advisory Committee, a major turnover of the Committee being anticipated. It is suggested that future LSAC members should, from time to time, review, revise, and update this Report, as a means of stimulating a continuing, dynamic vitalization of Life Sciences programs and activities.

The Report is organized in two sections; Section I is essentially the Report, itself, and Section II is a set of Appendices which provide discussion in depth of the various program areas of Medical Sciences, Biomedical Systems and Operations, Biological Sciences, and Payloads and Applications. The recommendations of the Committee are given in the Executive Summary of Section I; together with their accompanying rationales, these recommendations are presented in bare skeletal form, the detailed background being in the Appendices. Section I also contains a chapter on Status and Projections in relatively slender form and closes with Perspectives for what we hope will be a healthy future for the Life Sciences in NASA.

I wish to express thanks to the members of the Committee, and particularly to the Committee's Editorial Team, for their intensely interested participation in the preparation of this Report and, for the Committee, gratitude also to the many members of the NASA Life Sciences staff who provided extensive information and data, not merely during the time of preparation of this Report, but also in excellent briefings and discussions at meetings of the Committee over the past several years. I would especially like to convey the appreciation of the Committee to its Executive Secretary, Dr. Sherman P. Vinograd, for his untiring and meticulous efforts in the preparation of this Report.

G. Donald Whedon

G. Donald Whedon, M.D., ***Chairman***
Life Sciences Advisory Committee

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I. INTRODUCTION

Within NASA, life scientists have contributed to the survival and efficient performance of man in space and have raised the challenge of considering the origin and distribution of life in the universe. These activities have been important in the practical, as well as the intellectual, life of the Agency and of the Nation. The contributions which can be expected from these activites in the future depend on the efficacy and vigor of the programs within the Life Sciences Directorate, which has the responsibility of managing their development. This report contains general observations regarding the programs within the Life Sciences, suggests likely future directions, offers recommendations in the form of an Executive Summary, and concludes with Perspectives on functional responsibilities, relationships, and priorities. These comments and recommendations are supported by four appendices dealing, in detail, with the individual program elements.

The Life Sciences Advisory Committee (LSAC) has been in existence since 1971. By virtue of its three meetings per year at the NASA Centers and Headquarters, it has had the opportunity to be briefed rather extensively on all facets of NASA Life Sciences activities, and has come to know the personnel and facilities of the organization as well. Special Committee activities have enhanced this familiarity, e.g., both *ad hoc* and sustained LSAC consultation teams, liaison representation on proposal and RTOP reviewing panels, representation on National Academy of Sciences committees and special studies, and membership of Chairmen of the Committee on the parent NASA Council. This report to NASA management, the NASA Advisory Council, and interested participant groups and individuals summarizes the findings and recommendations resulting from our aggregate and, in our view, privileged experience.

II. PROGRAM DESCRIPTION

The goals of the Space Life Sciences Program are to:

1. Insure human health, safety, well-being, and effective performance in space flight.
2. Understand the origin and distribution of life in the universe.
3. Utilize the space environment to advance knowledge in medicine and biology.
4. Utilize space technology for application to terrestrial, medical, and biological problems.

The activities carried out in pursuit of these goals can be placed in four categories:

1. Research in medical sciences related to space flight.
2. Development of biomedical systems and maintenance of operations in support of manned space flight and aeronautics.
3. Research in the biological sciences, considering, in particular,
   a. the origin and evolution of life,
   b. the effects of gravity on biological systems,
   c. the prevention of biological contamination of the Earth and other planets, and,
   d. the environmental and ecological impacts of NASA activities.
4. The development of major projects dealing with
   a. space flight experiments, and
   b. terrestrial applications of space technology.

Structure and Content

The program is under the general direction of the NASA Director for Life Sciences who, in turn, reports directly to the Associate Administrator for Space Science. Within Headquarters, the Director for Life Sciences administers an office headed by four Program Chiefs. Both through these Program Chiefs and directly, the Director for Life Sciences is in contact with his counterpart at each of four field centers, namely Ames Research Center, Johnson Space Center, Kennedy Space Center, and the Jet Propulsion Laboratory. These individuals administer and coordinate activities in the Life Sciences at their respective Centers, obtaining funds for research operations through the Headquarters Program Chiefs.

The contents of these program areas are reviewed in detail in the appendices to this report. Briefly, we can observe that the program in "Medical Sciences" is devoted to problem-oriented research in medical and physiological fields of special interest in manned space flight. Research expenditures (FY 1978) in this area total $7.54 million, 22.6 percent of the total in Life Sciences, and are divided about 35/65 between in-house research programs and grants and contracts. More of the in-house programs are located at the Ames Research Center than at the Johnson Space Center. Roughly one-half of the ARC program supports out-of-house research, as compared with 75 percent at JSC.

The program in "Biomedical Systems and Operations" includes both medical support activities and a group of engineering projects. The former category includes development of crew selection criteria; the monitoring and maintenance of crew health; clinical activities, including development of instrumentation and consideration of pharmacological problems in space flight, and projects aimed at identifying design requirements imposed by human physiological characteristics. The engineering projects consider man-machine interactions very broadly and include investigation of teleoperator technology and life support and protective systems. Research expenditures total $5.15 million, 15.5 percent of the total in Life Sciences, and are divided about 25/75 between in-house projects and grants and contracts. Various components are found at ARC, JSC, and JPL, with personnel at those Centers directly administering most of the grants and contracts. JSC, however, maintains direct responsibility for flight medical operations.

The program in "Biological Sciences" includes activities in "Planetary Biology," "Space Biology," research aimed at preventing the contamination of Earth or other planets by non-indigenous organisms, and evaluation of the ecological and environmental impacts of NASA activities on Earth. Planetary Biology, an area recently brought over from the Planetary Program (a division of the Office of Space Science functioning at the same level as the Life Sciences Program), includes all activities (chemical and geological, as well as biological) aimed at understanding the origin and evolution of life on Earth and possibly elsewhere. In contrast, the work in Space Biology is primarily concerned with utilization of the space environment (primarily, zero gravity) for research on fundamental problems in biology. Research expenditures total $5.8 million (reduced to $4.9 million in FY 1979), 18 percent of the Life Sciences total, and are primarily devoted to the support of grants and contracts, although very significant in-house research activities in this area are maintained at the Ames Research Center. As a legacy of its origin in the Planetary Program, Planetary Biology administers most of its grants and contracts directly from Headquarters.

The remaining activities ($14.62 million, or 43.9 percent of the total expenditures in Life Sciences) are collected under the heading, "Payloads and Applications." Payload activities include collaborative activities with the Soviet space program or biological satellites in the Kosmos Series (two missions in the period 1973-1977, one or two more planned through 1981), and the early stages of an extensive series of Shuttle experiments. The Shuttle experiments will be allied with research activities already underway in the program described previously, chiefly those in the Medical Sciences and Space Biology. Present efforts are aimed at building the capability to perform a range of salient experiments in these disciplines. While the bulk of activities devoted to stimulating the transfer of space technology to human health-care are carried out within the Office of Applications, the Life Sciences Directorate maintains a small liaison activity in this area.

III. OBSERVATIONS ON NASA MANAGEMENT PERTAINING TO LIFE SCIENCES

The Management Process

The Life Sciences Program of NASA is not only complex and highly diverse, but also an extremely small part of a large Government agency. Furthermore, the goals, perspectives, personnel, and systems of the Agency are almost completely concerned with matters of engineering and "hard science." The extent to which the Life Sciences Program is overwhelmed by the main organization with an orientation so different presents complex problems, both psychological and real, for Life Sciences Program management personnel. Very important responsibilities for the Life Sciences staff are to describe, define, and interpret its programs to the Office of Space Science and to other top management of NASA, and to obtain an effective response.

Of lesser concern, but still an important responsibility, is interpretation and explanation of these programs to the Congress and to the general public. This matter is important to mention since even though the Life Sciences Program in NASA is relatively small, public and Congressional interest in the space program probably is at least as great toward the human, astronaut, and biological aspects as it is toward the physical sciences and engineering. Consequently, NASA management needs to pay close attention to appropriate, firm support of Life Sciences because of the usefulness to NASA for public relations and budgetary purposes of a positive image of Life Sciences.

Engineers and biologists (physicians included) have always had difficulty in understanding each other (almost as great a difficulty as between physicians and lawyers), not merely because of differences in language, but because of what is apparently a difference in style in carrying out their business. Engineers and physical scientists are generally involved in development of materials and substances which have characteristics capable of fairly exact and reproducible measurement. Biologists, physiologists, and research physicians deal with phenomena which are at least as complex but which are much more variable. The variety of such phenomena is attributable to the fact that biological systems are affected by a large number of conditions or influences, many of which are poorly understood, if understood at all. Data from life science experiments often show differences between means of series of measurements which have borderline statistical significance, or which may not be susceptible to *rigorous* statistical analysis because only a few observations can be made. Thus, the published biological paper or report many times cannot, or simply does not, contain all the information that peer scientists or managing project officers need for more complete understanding.

Experience has shown the value of frequent personal discussions. The life sciences, perhaps more than any other branch of science, are characterized by a particularly large range of annual and semi-annual meetings, often including informal "workshops" and highly specialized conferences.

Such discussion often becomes the basis on which next stages of research can be most efficiently planned and executed.

The characteristics of biological/medical research just described indicate the reason for the necessity for input of group expert advice on NASA biomedical programs. The fiscal impact of this necessity is, of course, mainly on funds for travel, for consultants, meetings of investigators, and effective monitoring of projects by Life Sciences staff.

Role of Advisory Committees in Management

The variety, subtlety, and complexity of the biomedical problems in the space programs, best illustrated by the uniqueness of weightlessness, mean that no single individual possesses the intellect, comprehensive knowledge of even a specialty area, nor the capacity for correlation and inspiration required to choose, advise, and manage projects in each program area. Probably due to both a shortage of travel funds and governmental management philosophy, NASA staff has tended to manage and direct various in-Agency and extramural studies in the Life Sciences area primarily within their own offices. They obtain limited advice from university or other outside scientists known for their knowledge and productivity in a particular field. For most productive management, however, a regular input of advice from consultant agencies is very important – advice both to program managers and to participating in-house and extramural investigators. As is mandatory in governmental agencies, the intent of advisory bodies should be truly helpful, nondirective, and advisory in every sense, with the authority for decisions and action remaining entirely with NASA staff.

A special advisory body relationship with NASA exists in the form of the Space Science Board of the National Academy of Sciences. Entirely independent of NASA, this body is charged with the responsibility of periodic review of the entire sciences program of NASA. Within the past year, a special subcommittee of the Board held a retreat at Snowmass, Colorado, to review the Life Sciences Program. A comprehensive report is in preparation.

The Life Sciences Advisory Committee had representation, through its Chairman, on the Space Program Advisory Council (SPAC). This latter body has been reorganized into a new group called the NASA Advisory Council (NAC), made up of the chairmen of six NASA committees, including the Life Sciences Advisory Committee, nine at-large members, and the chairman. Of the full membership, only the representative from the Life Sciences Advisory Committee is a bioscientist, again reflective of the distribution of NASA activities with emphasis on engineering and the physical sciences.

The Review Process for Scientific Projects

The process of management review of in-house or intramural programs is spelled out in memoranda of Drs. Winter and Vinograd in July 1976. The essential features are that high quality peer reviews are now conducted for both new proposals and the ongoing program on a regular basis. All work, whether in-house or out-of-house, is subjected to critical and qualified peer review. It must receive favorable review to be funded, and it must be satisfactorily reviewed every three years in order to be retained in the program. NASA Life Sciences and the Associate Administrator, Office of Space Science, are to be commended for developing this regular, systematic process which augurs well for both efficiency and correctness of decision. Members of advisory committees can be helpful in this process by participating to some degree in this periodic review of RTOP programs, both within Headquarters and in the Centers.

In the review process for scientific projects, the Life Sciences Directorate has certainly sought and used advice, but should consider seeking and using advice from varied disciplines more aggressively and imaginatively than it has to date.

As an example of imaginative action, during 1965-67, *one* of the program areas providing "grant" funds for life science related studies (at that time, such studies were funded and managed from three different NASA offices or divisions) arranged for scientific review of project applications by the "study sections" of the National Institutes of Health, final decisions on funding remaining, of course, in the hands of NASA management. These "study sections" are about 50 in number, covering various disciplinary fields from "Allergy and Immunology," through "Bioanalytical and Metallobiochemistry," "Biophysics and "Biophysical Chemistry," "Endocrinology," etc., to "Visual Sciences." Each group has 15-20 scientists, all but one or two from universities and research centers outside NIH. This system provides scientific *merit* (first level) review to the now 14,000 annual grant applications to NIH (amounting to more than $1.5 billion in awards). The system proved to be very useful to the Space Medicine Directorate of the Office of Manned Space Flight, which was the NASA program office involved. There were only minor problems related to relative unfamiliarity of reviewers with the special characteristics of space, weightlessness, etc.

In recent years, NASA Life Sciences has used for merit review four or five small review committees, some under AIBS sponsorship. There is a question as to whether there is sufficient breadth of real expertise within small committees of this type to give in-depth, sophisticated comment and review. AIBS has had prior experience with formation of larger review committees with considerable range, and should be able to provide the necessary improved service to NASA Life Sciences.

In general, the review process for initial application for "grant" funding and for similar formal renewal of such projects is well defined. The system for continued monitoring of progress and learning what new information has been produced is less clear. There is indeed a great deal to be said for the traditional grant (conditional gift) system (as used heavily by NIH), in which the principal investigator and his team, after initial review and approval, are pretty much "given their head" to follow where new observations "lead." NASA, however, has some special problems of weight and interest to suggest consideration of a more cooperative or collaborative approach, at least in certain areas.

To be more specific, in scientific areas where knowledge is sparse, as in Space Biology and Planetary Biology, the traditional, free-flying investigator's full-initiative style probably is best. In the areas of Payloads and Applications, in Biomedical Systems and Operations, and in important parts of the Medical Sciences, however, it not only seems quite possible, but even very likely, that more rapid progress would be made by a specifically organized coordinated approach among groups of investigators.

Observations on Professional Personnel

The diversity of responsibilities of the Life Sciences in NASA is reflected by the multidisciplinary nature of its Center and Headquarters professional personnel. The higher level degrees range from physicians trained in various specialties to doctorates in physiology, microbiology, geochemistry, biology, veterinary medicine, biochemistry, bioengineering, and others. Each of these fields has its own set of requirements for the achievement of excellence and standing within its own ranks. Because of the uniqueness of the space orientation of their work, and because of the inherent dominance of engineering and the "physical" sciences in NASA, there is a tendency for NASA biologists to become professionally isolated from their peers in their respective fields.

In the interest of retaining and attracting high quality Life Sciences personnel, NASA management would do well to be aware of the professional needs unique to each of these component fields of the Life Sciences and to fulfill them to the best extent it can. Postgraduate education, university affiliations, professional meeting attendance, research productivity and publications, and visits to other laboratories should be encouraged and supported. Growth of specialization in the field of space of various biological disciplines, as in the case of aerospace medicine, will also require the understanding and support of NASA management.

The present number of NASA life scientists appears to be just adequate in most areas, but some strengthening will probably be needed in selected areas as Shuttle/Spacelab demands increase. The question of inadequacy of secretarial and other support personnel merits attention as a possible deterrent to the efficient use of the professional staff.

When decreasing funds reduce the number of both in-house and contract professionals addressing issues in the life sciences, the opportunity for recruiting and training younger professionals also decreases. Consequently, the professional group becomes older and more professionally mature, but perhaps less innovative. If the life sciences research in NASA is to remain healthy, a vigorous mechanism must be developed to support graduate programs in critical areas and bright young professionals, both in the universities and at NASA Centers. One area in which trends in postgraduate education may affect NASA programs both in aeronautics and space has been the recent tendency to discontinue support of civilian programs training specialists in aerospace medicine. If postgraduate training in aerospace medicine becomes exclusively a function of the military services, the certification of this specialty by civilian professional associates will, under current bylaws, cease. The loss of aerospace physicians oriented towards commercial aviation and its problems will clearly decrease the capacity of NASA to address human issues in civil aviation.

As funding for life sciences programs in space decreases, there is a corresponding decrease in the number of young graduate students with detailed familiarity with the problems of direct concern to the Life Sciences. The use of mini-grants, postdoctoral resident educational techniques, and the support of contractors at NASA Centers should be encouraged to counter these trends. These methods serve not only to provide laboratory assistance when needed, but also as a means of recruiting and training professionals. In the long run, NASA Life Sciences management must concern itself with its role in encouraging the training and development of professionals who will carry on its mission in the future.

The Budget Process

As is true for all Government departments and agencies, NASA's funds are appropriated for a single fiscal year and the exact amounts available may not be known until just before the start of the year, or even occasionally, after the year has begun. "No-year" or multi-year funds are apparently rarely appropriated, at least in the Life Sciences Program. In addition, legislated authorities for NASA programs are in all, or nearly all, cases limited to one year. Hence, NASA officials must appear each year before four Congressional Committees (legislative and appropriations, in both the House and the Senate) to justify their authority to conduct their programs and then to obtain the funds needed to do so. Prior to these appearances, of course, officials must justify the proposed funding of their programs before examiners of the President's Office of Management and Budget (OMB) before acceptance within the President's budget for each year. As a consequence, NASA officials, including Life Sciences staff, spend considerable time each year in preparation of testimony for OMB and Congressional hearings; time necessarily taken away from regular work. Even more disturbing to effective work production is the continuing year-to-year uncertainty of the viability, both relative and absolute, of various projects and programs on which considerable planning and developmental effort may have been expended. If judged essential, such efforts often have to be continued just on the possibility that active support funds may be forthcoming later.

Since it is a small part of the Space Science budget, it might be thought that Life Sciences is at least partially hidden and hence protected. Actually, however, Life Sciences budgets seem not to be particularly protected, and when cuts are made, entire small programs may be eliminated (e.g., Circadian Rhythms). The NASA Director for Life Sciences has a voice only within the Office of Space Science in the decisions as to which projects are to be reduced or scuttled; he has no scheduled budget voice at any higher level within NASA. Furthermore, Life Sciences is neither large enough nor prominent enough in NASA to merit a witness seat before the various Congressional Committees and thus is unable to respond directly to questions from the authorizing and funding sources. It is by no means certain, of course, whether the Congressional ear would be any more sympathetic, but in days of tight budgets, Life Sciences should be quite willing to be permitted to take the risk.

A further unhealthy influence on Life Sciences Programs via budget processes is the effect of steadily mounting inflation. Neither OMB nor Congressional appropriations committees are apt to build in automatic increases to compensate for the declining purchasing power of the dollar; yet a six to ten percent increase is really necessary each year to enable Life Sciences to continue projects at the same level of effort. This effect of inflation is not unique to any program in NASA or the Government, but its influence on Life Sciences in no less.

Conclusion

An overall view of Life Sciences problems and operations suggests that benefit and possibly a greater degree of support and progress might result from (1) more use of consultant advice for assistance in program decision-making, (2) somewhat broader, more varied expertise in review of merit, content, and direction of individual projects (both in-agency and extramural), and (3) development of a system of close, regular communication among investigators in particular areas, between investigators and advisors and among investigators, advisors, and management, for more rapid exchange of new information and perhaps development of more inspirational ideas in this thoroughly interesting and highly important program.

IV. STATUS AND PROJECTIONS

Medical Sciences

The Medical Sciences portion of the Life Sciences Program is concerned with providing the information necessary to ensure human health, safety, well-being, and effective performance in space by the development of criteria for selection, methods of disease prevention, countermeasures, and effective treatment. Thus, the Medical Sciences primarily support the first goal of the Space Life Sciences Program. In order to do this, studies must be carried out in both human volunteer subjects and in appropriate animal models.

When, almost 20 years ago, plans were initiated to send man on prolonged journeys in space, there were those who felt that man would never be able to survive in this weightless, hostile environment. This prediction proved to be incorrect. Many anticipated problems associated with living in space are no longer of concern. The following brief description of the status of the medical sciences deals with our current knowledge of those matters most likely to influence the health, well-being, and effective performance of man in space. (See Appendix A for a more detailed description.)

Bone and Muscle

Studies in Skylab have demonstrated that deterioration of bone and muscle integrity do occur under conditions of weightlessness. No reversal of this process appears to occur so long as the person remains in the weightless state. Although it would appear that artificial gravity should prevent this problem, one recent animal experiment indicated decreased new bone formation in spite of the presence of artificial gravity provided by centrifuge. Clearly, the loss of bone and muscle tissue becomes an increasing problem as man remains in space for longer and longer periods. The loss of bone and muscle mass might progress to the point of severely incapacitating an individual returning to gravitational conditions.

Fortunately, chronic bed rest is a reasonable model for studying bone and muscle changes which occur in space. This provides an opportunity to increase our knowledge of the mechanisms of bone and muscle loss. At present, no effective countermeasures are available to prevent bone and muscle loss in weightless conditions. Current information concerning bone loss in hypogravity is relatively advanced over our knowledge concerning the mechanisms of muscular deterioration. Research concerning bone and muscle integrity deserves a moderate increase in funding and increased emphasis on muscle loss. Increased utilization of expertise from outside consultants will be needed to establish an effective muscle research program.

Cardiovascular, Fluid and Electrolyte, and Blood

Immediately upon entry into weightlessness, fluids and electrolytes are redistributed in the body as fluids that normally pool in the legs are shifted centrally and to the head. Cardiovascular mechanisms that maintain blood supply to the brain during upright posture under conditions of 1 g are compromised. It would appear that most of the changes observed in blood constituents occur secondary to these fluid shifts. These changes appear to facilitate adaptation to weightlessness but, upon return to Earth or planetary conditions, increase risk of postural hypotension (gravity shock) and unconsciousness. In addition to these acute changes, difficulties in maintaining upright posture continue for several days as readaptation to gravity occurs.

While the changes observed in the weightless state appear to be benign, some of them, such as a potential increase in pulmonary arterial pressure, require further documentation and study. The only operational countermeasure at present is the anti-G suit. Additional countermeasures such as fluid and electrolyte replenishment methods are under development at the present time. In the long run, the benefits and costs of providing artificial gravity or of preventing untoward cardiovascular or fluid and electrolyte changes during prolonged space travel require investigation. In general, future research efforts should concentrate upon the mechanisms that influence cardiovascular stability upon return to gravitational influences. Integration of data across RTOPs is particularly to be encouraged in this area. In the past, research concerning blood constituent changes in space has not appeared to be as convincingly organized as other programs. Recent peer review has resulted in modification of this program as recommended by these outside experts. Similar reviews for all elements of the program continue to be indicated on a regular basis.

Radiation

As man goes beyond the protective atmosphere of Earth, he is exposed to an entire gamut of radiation hazards. Onboard reactors could serve as an additional source of radiation risk. Most of these risks are adequately investigated by agencies other than NASA. Of unique concern to Medical Sciences are HZE particles (cosmic rays) which possess the capacity to kill living tissue as they pass through it. This is probably a problem largely for non-replicating tissue such as the central nervous system. Most biologically significant of the HZE particles will have an atomic weight of around 26 and efforts are underway to generate such particles at appropriate energy levels from accelerators. This effort is critical to the development of an estimate of the nature of the risk created by these particles in the dosages encountered in space. Although HZE particles need not prevent long duration manned missions, the development of estimates of the risk factor and appropriate countermeasures (shielding) is proceeding as required. In general, this research area is well organized and attracts reasonable numbers of investigators. Moderate increases in funding should be used to achieve slight expansion of this research effort.

Space Motion Sickness

It is clear that space motion sickness is primarily a problem of short flights. It is self-correcting after one to four days. Present pharmaceutical countermeasures may help, but fall short of correcting the condition. Further, these countermeasures themselves carry at least some potential side effects. An improved understanding of the mechanisms of space motion sickness is being pursued to improve this situation. At least one innovative training procedure is being pursued that will allow the crew member to suppress the symptoms of space motion sickness. The use of parabolic flight as a model for prolonged weightlessness in space does not appear to be well justified although new approaches for the utilization of this tool are promised. This research effort is well-organized and appropriately funded. The researchers are generally of high quality.

Performance

This small program currently addresses issues relevant to the organization of working space teams and the incorporation of women into these teams. Factors relating to the organization of groups and social behavior are being investigated to facilitate methods of selection, training, and operation of crews. Simulations of space flight are used as research models. A single study of the effect of circadian changes upon human physiologic response and performance remains in the program. If any long-term space flight (a Mars mission or a residential space station) is contemplated, the behavioral performance area of research would require expansion. Currently, it is directly contributing to the selection and organization of space crews for travel on the Shuttle. The effort is appropriately organized. Funding is generally appropriate, but a modest increase should be considered for one or two psychosocial studies to be added.

Preflight Detection of Infectious Disease

This area of research can provide improved methods for detecting infectious disease in human or animal passengers prior to launch. Present state-of-the-art should allow considerable improvement in the accomplishment of such detection. Currently this effort is under-funded and probably underdeveloped for the needs of NASA.

Medical Sciences Overall

This portion of NASA Life Sciences research efforts is generally well-organized and demonstrates reasonable progress toward increasing knowledge and developing new solutions to difficult health problems associated with manned space flight. Overall resources available to this program are marginally adequate. Unless there is a moderate increase in funding and a continuing commitment to the recruitment of young professional personnel to the in-house program, the long term outlook for this program is not sanguine. The Medical Sciences program overall can benefit from redirection of its program in a few areas and moderate expansion in addressing problems related to *Bone and Muscle*, *Radiation*, and *Preflight Detection of Infectious Disease*. For the

Medical Sciences program to yield its maximum benefits, it should not only seek advice from the best experts in Medical Sciences outside of NASA, it must also improve its capacity to utilize the considerable talent at the various NASA Centers. This cannot happen unless travel budgets are increased. Finally, it appears that current leadership and management within NASA Life Sciences programs in the area of the Medical Sciences are quite superior.

Biomedical Systems and Operations

Medical Selection Criteria and Crew Health Monitoring

Although much has been learned about the effects of space flight on human performance, improved procedures need to be developed to identify levels of susceptibility to space flight factors. Susceptibility to space motion sickness is most significant, particularly since early Shuttle flights of short duration will be employed. Most of the documented effects of space travel will not produce significant health hazards in short duration Shuttle flights, but latent pathology, such as coronary disease, must be identified and quantitated.

The requirement for extreme alertness in the Shuttle program makes the maintenance of health of astronauts of great importance. This state of health must be defined and monitored and access to quality health care made readily available in flight. Definite physiological changes are involved in adaptation to the weightless state and a complex reversal occurs on readaptation to the 1 g state. Preventive measures, drugs, and exercise have been used, but more attention needs to be paid to nutritional considerations, especially for longer duration flights.

Physiological Design Requirements

The SR&T to establish physiological design requirements and standards provides an essential supportive data base to the development of both near-term and advanced life support systems. It is designed to generate information, permissible standards, and scrubbing requirements for toxic products and toxic pyrolysis products; dysbarism prevention standards for extravehicular suit transfer and space flight decompression; system performance characteristics and requirements; and standards for gaseous and thermal control. These efforts are operational necessities for the adequate support of both nominal and non-nominal flight conditions.

Advanced Teleoperator Technology

The public, as well as the scientific community, seems generally to appreciate the advantages of direct human presence in space – to see, touch, and manipulate the environment spontaneously, as compared to having programmed machines collect and process data for return to Earth. What is generally not appreciated are the developing capabilities for remote communication and control technology to enable a person on Earth to inspect and manipulate that same space environment – to extend his nervous system and feel a real sense of presence in the remote location. The life science implication of such remote human participation should be made more apparent within NASA. The potential for teleoperators to achieve specific missions reliably and cost-effectively should be explored systematically by joint life science and engineering teams.

Understanding of what teleoperators can and cannot do has been hampered because such developments in the past have been tied to specific operational missions and not viewed as legitimate scientific research. We believe that the many questions (listed under discussion of this research area in Appendix B) should be viewed as fundamental research questions with a strong life science component. (See "People vs. Computers," page 15.)

Man-Machine Engineering Requirements

NASA research in man-machine engineering requirements is a broadly directed effort to improve the discipline and art of designing man-machine interfaces and displays, controls, habitability, spacecraft interior layout, work routines, crew assignments, mission simulations, and techniques for collecting human performance data. The overall discipline is still in its primitive stages. The research addressed to these many interactive concerns merits continuing support, provided the experimental questions are well formulated. The process of regular program reviews can be helpful in this respect. Liaison with other man-machine interface research, such as the DoD project on Integrated Computer Aided Manufacturing (ICAM), should also be encouraged.

Advanced Extravehicular Systems

Impressive strides have been made in space suit design and extravehicular life support systems, but there is a continuing need for more reliable, comfortable, mobile extravehicular systems with suit pressures approaching 14.6 psi (sea level). There is also a need for effective integration of these systems with improved hand and power tools and a need to clarify design trade-offs, especially those involving increasing suit pressure, metabolic loads, and safety. Continuing research and development in this area is essential to any future manned space flight endeavors.

Advanced Life Support Systems

Manned space missions, to date, have utilized open life support systems. That is, there has been no system used for regeneration of food, water, and oxygen. Long duration missions will necessitate the use of partially, or completely, closed life support systems. With this in mind, efforts have been made to develop physical and chemical processes for water reclamation, carbon dioxide concentrators, oxygen regeneration from carbon dioxide, food preservation, waste contaminant control, and nitrogen regeneration for atmosphere resupply.

Closed ecological life support systems (CELSS) will require consideration of biological components, such as in the food chain. Closed chamber studies have been made in phytotron and biotron facilities, and their relevance to CELSS needs to be investigated. Much information needs to be obtained concerning the following areas of technology: atmosphere control and regeneration, water purification and reuse, waste control and conversion, and food production and processing. Progress in these areas will require basic research in several more conventional areas such as microbiology, plant and animal physiology, agriculture, and closed system ecology.

Aerospace Medicine and Safety

This category, consisting of three research tasks for which OAST is now responsible but the Life Sciences Directorate reviews, is clearly of growing importance. As air traffic increases around certain metropolitan areas and the demand grows for all-weather operations, problems of navigation (reading maps) and communication (voice) have placed an increasing workload on the pilot. Use of computer-based displays (integrated graphic and alphanumeric) and direct communication between aircraft and ground-based computers is now technologically feasible. However, design and policy decisions hinge on a better understanding of what is best for the pilot, i.e., when more information is a hindrance rather than a help, how many crew are necessary on the flight deck, and how responsibility should be divided between pilots and ground controllers.

For these reasons, we recommend expansion of such aerospace programs and closer cooperation between life sciences and engineering components within NASA (as well as with Air Force and FAA) with the aim of clarifying the advantages and disadvantages of further automation, the relative roles of man and computer, and the ability of man to detect, diagnose, and remedy sudden failures of automatic systems.

People Vs. Computers

Somewhat apart from the program elements reviewed above, we have a growing general concern about the future wide-ranging life-science implications of "people-vs-computers" within NASA. In coming years, due to rapid progress in development of cheap and miniaturized computer hardware and sophisticated software, the pressures will be tremendous to automate the human organism out of aerospace systems of all kinds. As discussed above, sometimes this automation will take the form of autonomous "robots" for planetary exploration, and the question of people-vs-computers will be apparent and well drawn. More often, as in commercial and general aviation (both piloting and traffic control) and in ground tracking and satellite communication networks (a big chunk of NASA's budget), automation will be distributed, more subtle, and much less apparent; and many people will be interacting simultaneously to effect control of messages or vehicles.

Some of the pressures to automate will be motivated by the technological imperative – "We can replace people so we should." Some will be crass commercial pressures. It almost seems that retention of the human organism is accepted for reasons of sentiment and vague concern that he be available to "back-up" automatic systems. Yet there is increasing evidence that unless a person can actively participate as a controller or observer, he cannot, in effect, "come off the bench cold and get into the game" with ease and reliability. Are people to be removed from aerospace systems entirely – except as passengers – or is there a proper balance between people and computers? We are told that what people do best and what computers do best are different, and in fact complementary. But the intellectual disciplines for proper integration of man-machine systems are not well developed – except in a very few specific areas of motor skills, signal detection, and other behavioral areas where DoD has supported continuing research.

The concern for NASA Life Sciences is a fundamental one. There are various specific people-vs-computer problems which arise in aviation safety, management of communication networks, construction of large solar arrays in space and planetary exploration. The main point is that these problems have in common the functional allocation or roles between living organisms and computers despite their specific dissimilarities from one application to another. These problems probably have more to do with life sciences than with physical sciences and technology. Yet they remain ill-defined.

The interdisciplinary nature of the situation provides further aggravation. Within the NASA bureaucracy, it has never been very clear where the responsibility for such concerns should lie. A current NASA task force on "Robotics and Machine Intelligence" under the chairmanship of Carl Sagan is now discussing the above question of people-vs-computers to a degree, but its emphasis has been more on making computers more sophisticated and "intelligent" than on utilizing the perceptual, motor, and cognitive skill contributions of human organisms vis-a-vis computers in *semi*-automated systems (which really includes most NASA systems).

Some basic life science questions which remain unanswered are:

(1) How should the error and reliability of the human operators and human monitors be characterized and measured? Is the assumption of "independence of component failures," now widely employed in nuclear plant reliability analysis, valid for human errors such as may occur in NASA's systems?

(2) How can or should mental (as distinguished from physical) "workload" of pilots, air traffic controllers, astronauts, and scientific observers be measured? How does automation affect mental workload, especially as regards "alertness," anxiety about status of inferred variables, "trust," and the ability to "take-over" when called upon?

(3) How to arrange displays of large amounts of computer data for speed and reliability of detecting or diagnosing faults?

(4) Under what circumstances should people supervise computers and under what circumstances should computers supervise people?

(5) What are the feasible dynamics of "trading" and "sharing" control between people and computers beyond the crude interchanges now prevalent in using time-shared computers through typewriters? Natural language interaction is now available, but we know little about how to use it.

Finally, in view of the fact that many of the above-mentioned man-machine activities necessarily involve life sciences and engineering disciplines, in consideration of the relatively primitive state-of-the-art, and because of the fragmentation across various administrative components of NASA, we recommend that a small ad hoc task group be constituted specifically to address the following questions and make recommendations.

(1) What underlying scientific discipline needs to be developed in man-machine interaction, which aspects of such disciplines should NASA be responsible for developing, and which should be left to other agencies? What are the gaps in current NASA efforts to develop such disciplines, and what are the strengths?

(2) Which NASA projects or activities in this area would benefit from closer coupling, and which projects or activities must necessarily be left independent of one another?

(3) What administrative arrangements can best serve to integrate NASA life sciences and engineering efforts to achieve these ends?

Biological Sciences

The programs in the biological sciences can be contrasted with the more medically-oriented activities which dominate the Life Sciences Directorate. The medical programs are all motivated, however distantly, by operational requirements associated with manned space flight. These programs are, in this sense, more "practical" or "applied" than those in the biological sciences, a distinction which has at least two effects. First, the status of the biomedical programs can be judged in terms of the limitations which must be imposed on manned space flight at any given time. Second, in spite of their variety, the various components of the biomedical program share an underlying unity; that is, they are all aimed at the support of man in space. In contrast, the fundamental research in the biological programs cannot be evaluated in terms of progress toward applied goals, and some of the programs are genuinely divergent.

Space Biology

The program in "space biology" might be more descriptively titled using the term "gravitational biology." It is principally concerned with answering the question, "What role does gravity play during the growth, development, function, and evolution of organisms?" This question has not yet been satisfactorily answered in Earth-based laboratories, since the effects of terrestrial gravity are too persistent and pervasive. Adequate experiments allowing observation of organisms in an environment truly free of gravity can be envisioned only in space, and this fact has motivated the Agency's involvement in gravitational biology.

Several flight programs have already been devoted to space biology. A principal result has been an expanded appreciation for the refractory nature of studies in gravitational biology. While investigations on Earth have been unable to provide a truly weightless environment, those in space have been unable to provide the truly Earth-like environment required for an adequate control. The failure or absence of a number of environmental subsystems has made decisive interpretation of the flight results impossible, and as a consequence, space biology has gotten a "bad name" in some quarters.

The future of space biology can be a much happier subject. The Spacelab will provide facilities of far greater flexibility and much better quality than previously available, largely because of the presence of well-trained scientists aboard. The attraction which this opportunity holds for high-quality investigators is already evident. At the very least, the possibility for noteworthy contributions in this area exists, and there is every reason to expect that the lessons of the past have been learned so that many problems can be avoided. Amidst this optimism, however, we will observe that the best evolutionary pathway for studies in this field both within and outside of NASA will require some careful planning. We have addressed this topic in later sections of this report.

Planetary Biology

This program is concerned with the origin and evolution of life on Earth and with the possible presence of life elsewhere in the universe. It has addressed these questions through investigations of the non-biological chemical reactions that might have spontaneously produced organic compounds prior to the origin of life, thus providing the "building blocks" from which the first self-replicating systems were derived; through active searches for life on the surfaces of the Moon and Mars; and through investigations of meteorites and of the oldest rocks which are accessible on the surface of the Earth. Related investigations supported both within NASA and by other agencies are directed toward reconstructing the chemistry of the volatile elements during the condensation of the solar nebula and the accretion of the planets, and toward explanation of the origins and relative abundances of interstellar organic molecules.

It can be said that planetary biology is at a turning point. No new searches for life elsewhere in the solar system are likely to be undertaken in the near future. Studies of prebiological chemical reactions must reach new levels of detail to avoid repetition. Preliminary surveys, at least, have been made of the organic constituents of all available carbonaceous meteorites and of representatives of all the major Pre-Cambrian sedimentary systems. Future work in this program must break new ground by increasing the depth, not the breadth, of the various lines of inquiry.

The nature of the exploratory phase, now ending, has been such that a particularly productive future can be predicted for this field. One principal trend which has become evident and which should be especially important is the integration of planetary biology with allied fields. Close attention is being paid to geophysical and geochemical evidence regarding the conditions which must have prevailed on the early Earth and during the formation of the carbonaceous meteorites. Within these allied fields, it is being recognized that the element carbon provides an especially versatile tool for deducing early chemical and physical conditions, and cooperative investigations involving, for example, planetary biologists and astrophysicists are developing. A deepening of the theoretical foundations underlying planetary biology can be expected, and the field seems destined to gain substantially in maturity and strength, generally becoming a driving force in the development of new information in space science.

Other Programs in the Biological Sciences

Responsibility for the U.S. program in "Planetary Protection" lies in this program area. The microbiological cleanliness of American interplanetary spacecraft is monitored, and contact is maintained with the international bodies which set requirements aimed at minimizing the possibility that terrestrial microorganisms might inadvertently be flown to and contaminate another planet. Future activities in this program will play a key role in the planning of missions aimed at the return of samples from the surface of Mars.

Programs dealing with ecology and with the environmental effects of the Space Shuttle are discussed in Appendix C. The Program Chief in Biological Sciences does not manage these specialized activities. The status of the program in ecology, originally envisioned as an adjunct to the development of closed life support systems, is uncertain at this time. The work aimed at evaluating the environmental effects of the Space Shuttle launch activities at Kennedy Space Center will be continued at a level dictated by programmatic and legal requirements.

Payloads and Applications

Life Sciences Flight Experiment Program

In 1981, NASA will begin the space flight phase of the Shuttle-Spacelab program, a NASA activity of extreme importance because of the quantity and quality of new scientific information which is expected to be obtained. Although the level of ideas, plans, and the caliber of investigators are probably the most important factors in the Spacelab program, success cannot be achieved without strong operational support. In the Life Sciences segment, the principal support effort is the development and production of common laboratory equipment and in the screening, organization, and operation of the experiments themselves.

In the equipment effort, both design and production of the common animal research facility are proceeding on schedule. A specialized plant experimental facility of limited scope and flexibility is being prepared. The plant facility, as presently planned, will have limited ability to support other plant investigations.

Solicitation of experiments from the scientific community has proceeded with a series of Announcements of Opportunity to conduct experiments in space issued to potential investigators in all fields. Although Life Sciences is only a small part of the total NASA scientific activity, about 40 percent of the responses to date have come from life scientists. Such a vigorous response holds promise that quality and caliber will be high in the Life Sciences Spacelab studies. A series of panels of scientists has been organized to review the formal applications now being submitted. Later, NASA Life Sciences staff will need to devise a system by which high quality investigators with similar or closely related research study plans can be grouped together in teams for maximal efficiency and productivity.

In the immediate future, it is critical that facilities to support research be developed for *both* plants and animals. The best and most flexible set of facilities must be developed in order to provide full opportunity for success in the Medical Sciences and Gravitational Biology programs.

Vestibular Function Research

This experiment is an effort to learn more about the mechanism by which vertebrates sense and adapt to gravity. Hence, it may help ultimately toward solution of the problem of space sickness. Plans are in preparation for its conduct on the Spacelab III flight of June 1981. Construction and engineering evaluation of a prototype experimental unit are scheduled.

Kosmos

U.S. scientists have thus far participated in two U.S.S.R. Kosmos flights. The experiments on board have yielded significant results, particularly with respect to the phenomenon of bone loss in space. Decreased bone growth was observed in young animals. Experiments for participation in future Kosmos flights are being planned with perhaps some improved capacity over that available in the first two flights. A serious limitation for U.S. investigators is their physical separation from the experimental vehicles (both flight and control) and the lack of access to the experimental packages by anyone for a considerable number of hours before and after the flights. In addition, experimental procedures on tissues and animals after flight are not within the control of U.S. investigators. An improvement in such conditions is essential for improved quality of experimental results, but such a change is not predictable at present.

Clinical Uses of Space and Biomedical Technology Applications

Efforts are just getting underway to inform the medical research community of opportunities to begin research on the two objectives: (1) medical research uses of space (examination of basic mechanisms of disease with the aid of the unique weightless environment) and (2) clinical uses of space (investigation of the space environment for potential use in treatment of disease). Many projects are being supported by the technology utilization activity of the Office of Applications under a third objective, development of medically related space technology and its application to diagnostic and therapeutic clinical medicine and medical research on Earth. Continuation of efforts on this latter, very practical, objective is easily projected, but the future course of activities along the novel and highly specific objectives of medical research and clinical uses of space is very difficult to predict. Because of the possibility that projects in this program will provide specific, unusual, and useful spin-offs of space technology to Earth medical research and practice, all three objectives should be pursued.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Introduction

The Life Sciences Program of NASA is complex, highly diverse, and fundamentally important to NASA's major goals. The importance of the program lies mainly in its support of basic biological research relevant to space and of studies to supply the knowledge necessary to maintain the health of man whenever and wherever he goes in space. It supports and facilitates the national life sciences community in its utilization of space for scientific research, and it facilitates advancement of specialized areas of fundamental and forward-looking research in biology, the medical sciences, and biomedical technology which fall uniquely within NASA's goals and objectives. The Life Sciences Program is central to these NASA responsibilities as well as to certain specific issues, such as planetary quarantine and protection, and to several supporting functions, such as providing guidance and direction on biomedical aspects of technology utilization, Earth resources applications, and Earth ecology concerns and obligations. The human aspects of this program, as well as concerns about the development of life in the universe, give the Life Sciences a significance out of proportion to its size because of public and Congressional interest in these matters.

In the view of the Life Sciences Advisory Committee, from its analysis described in this report, NASA should provide more attention and firm support to this program and should develop ways for it to function more effectively.

The Committee believes that the most useful way to epitomize its review and make it meaningful to NASA management is to present a series of recommendations, each followed by its rationale (in *italics*). This summary begins with a presentation of general recommendations concerning the operation and management support of the Life Sciences. This is followed by similarly presented recommendations relative to each of the major segments of the Life Sciences Program: Medical Sciences, Biomedical Systems and Operations, Biological Sciences, and Payloads and Applications.

General Recommendations

Modification of NASA Organization for Life Sciences

The Life Sciences Advisory Committee recommends that the Administrator of NASA appoint a special task force, including life scientists, to review and make a specific recommendation on the location or relocation of the Life Sciences Program in NASA's organization.

Considering the extensive diversity of responsibilities of the Life Sciences, this Committee recognizes the administrative difficulties involved in establishing a perfect location for the Office of Life Sciences within the NASA organizational structure. The Life Sciences is inherently an administratively anomalous organization within NASA in that its functions cut horizontally across major organizational lines. Past experience with other, divided, organizational arrangements has shown that a single united NASA Life Sciences (and consequently preservation of this anomaly) is a necessity in the interest of efficiency, economy, and coherence of its work. The anatomical and *physiological reasons for this necessity reside, basically, in the fact that the Life Sciences is a small disciplinary identity in an agency which is devoted predominantly to the physical sciences and engineering, and is organized accordingly. While these "hard" sciences are so heavily represented in the Agency that their division into functional and subspecialty areas is mandatory for efficient operation, the Life Sciences is too small and becomes too fragmented for efficient function if it is similarly divided. (The same would be true of a physical sciences effort in a life sciences agency.) Yet, despite its limited size, the NASA Life Sciences is indispensable to NASA's goals and Agency operations.*

The Life Sciences Advisory Committee acknowledges the logic of the present location of Life Sciences within the Office of Space Science for operation in association with essentially all other scientific research activities at NASA. The Committee strongly recommends, however, that because of the great diversity of Life Sciences responsibilities, the special importance of medical staff to space flight operations, and the unique importance of biomedical scientific activities to both the science and the operations of long duration/planetary space flights, the NASA Director for Life Sciences should have direct access to the Office of the Administrator, NASA, for planning and budgetary consultations. Prior to the last reorganization, the Life Sciences Directorate had a "dotted line" relationship with the Office of the Administrator, and, in addition, the Director for Life Sciences appeared regularly as a witness before Congressional subcommittees and thus had the opportunity to justify and explain the significance and importance of biomedical research and operations. Life Sciences carried the title "Office" and was headed by a "first line" director, thus allowing a higher level of management relationships for all of its internal working levels and greater prestige value for the aerospace life sciences disciplines.

While, indeed, there may be other possibilities for more suitable organizational arrangements, serious consideration should be given to at least two alternatives: maintenance of Life Sciences in its position in the Office of Space Science, but with a means of ready and frequent communication with the Office of the Administrator, or movement of Life Sciences from OSS to independent Office status reporting directly to the NASA Administrator.

Goals for the Life Sciences

Among the present goals of the Life Sciences Directorate, the fourth, "Utilize space technology for application to terrestrial, medical, and biological problems," should either be modified by adding the following words " . . . in liaison with related programs in other activities in NASA" or be dropped.

While there is a sound rationale for involvement of Life Sciences personnel with related programs elsewhere in the Agency, Technology Utilization and Biological Application of Remote Sensing providing two examples, such activities should be carefully limited. The specific roles and responsibilities of Life Sciences personnel should be mutually and formally agreed upon at all relevant levels of the Agency. The fact that these liaison activities are secondary to the principal responsibilities of the Life Sciences should be recognized.

Among the present goals of the Life Sciences Directorate, the third, "Utilize the space environment to advance knowledge in medicine and biology," should be changed to

"*Stimulate* and *facilitate* use of the space environment to advance knowledge in medicine and biology."

A basic NASA goal is noted as the "Development and demonstration of techniques and systems . . . exploiting the characteristics of space . . ." in order to contribute to "human well being." Care should be taken, however, that these activities do not lead the Agency too deeply into an endless variety of scientific disciplines in which the "characteristics of space" might be usefully "exploited." Life Sciences programs undertaken to fulfill this goal should be limited and chosen to be consistent with the concept of demonstration. The terms "stimulate and facilitate," as opposed to "utilize," are viewed as significant in this context. (It should be noted that the Agency goal quoted also calls for "transfer of technology" and "provision of operational assistance" to "other organizations, both public and private" in accomplishing this objective.)

Communication and Collaboration

Life Sciences should develop a system of close, regular communication among investigators in particular scientific areas (involving both NASA "in-house" investigators and outside NASA-supported investigators), between investigators and non-NASA advisors, and among investigators, advisors, and NASA staff, for more rapid exchange of new information, increased production of new ideas, and development of improved research plans.

Survey of RTOP descriptions of SR&T projects reveals that in certain program areas (e.g., musculoskeletal studies) there are projects on closely related or the same subjects located at different NASA Centers as in-house research or supported by grant/contract by different NASA Centers. These studies would likely benefit from a coordinated organization of the scientists working on these common problems. A regular system of exchange of developing research results might facilitate or speed up progress in comparison with that of the current laissez-faire system. It must also result in development or revelation of critical scientific research questions and ideas, and potentially lead to a considerably more productive program. Such meetings or conferences should include selected consultants and investigators in the field who are supported by other agencies in order to obtain the most complete, up-to-date exchange of information.

As specific suggestions, annual meetings could be held of the involved investigators and pertinent advisors. Less often, larger workshops of 30-40 scientists should be held on particular subject areas. Scientist-astronauts with biological or medical experience should be included and other scientist-astronauts invited.

In addition to the suggestions above for new communications activities, liaison should be continued and extended between LSAC and other NASA standing committees. Periodic meetings or other contacts between LSAC and corresponding committees of the Space Science Board, National Academy of Sciences would also be useful.

Use of Consultants

The Life Sciences Advisory Committee (LSAC) recommends that NASA Life Sciences use consultant services more actively in two particular activities:

(1) Advice to the NASA Director for Life Sciences and to the directors of Life Sciences activities in the Centers on planning, direction of effort, emphasis, and priorities; and

(2) Review of SR&T grants and contracts, in a more regular set of review committees. These committees should be of sufficient size that greater breadth of expertise is made available for in-depth sophisticated comment and review.

What is suggested is that, in addition to the regular, three times a year meetings of LSAC, the NASA Director for Life Sciences would benefit from periodic, ***ad hoc****, one- or two-day meetings with a small number of consultants, either on a particular problem area or on overall Life Sciences strategies on several matters. The reason for this suggestion is that the Director is relatively isolated from biomedical/bioscience input, both from the administrative and scientific points of view. Such consultants could either be members of LSAC or not, depending upon the nature of the particular need for their advice. Members of LSAC, from their own experience, are aware that "Directors" are not fond of advice which would appear to be directive or supervisory. Thus, it is understood that, as is mandatory in governmental agencies, advisory groups are solely advisory, with the authority for decisions and action remaining entirely with NASA staff.*

In recent years, NASA Life Scienes has used, for merit review, four or five small review committees, but meetings tend to be irregular because of variations of in-flow of applications. The latter problem may not be remediable, but larger sized committees seem necessary to provide adequate breadth and depth of expertise. During 1965-67, NASA's former Office of Space Medicine arranged with the National Institutes of Health for NIH study section reviews, a system which apparently worked well. Development of a similar system of regular review, with a much smaller number of "study sections," could be investigated. Probably the most logical solution would be the expansion in size and number of AIBS Committees. Peer review of this type has been generally acclaimed, both as fair to applicants and as most likely to guarantee to the supporting agency the highest quality of research effort and of investigators.

To the extent that funds permit, quality of review would be aided by reviewer site visits in selected cases.

Budget Planning for Life Sciences

In presenting budget proposals to the Administrator of NASA and then to the Office of Management and Budget, NASA management should build in annual increases to compensate for the effects of inflation, particularly in many programs in the Life Sciences which are of such small size that vitality would be all but extinguished by year-to-year level budgeting.

The effects on all types of Government programs of the declining purchasing power of the dollar are well known. Such effects are at least as great on Life Sciences. A six to ten percent increase each year is necessary to enable Life Sciences to continue projects at the same level of effort.

It would be advantageous to NASA's Congressional and public relations, particularly with respect to budgets, for the NASA Director for Life Sciences to appear on appropriate occasions as a witness before Congressional subcommittees.

Travel Funds

LSAC repeats its concern over the level of allowances for travel in the Life Sciences Program.

The Committee expressed concern on this matter in 1977, and some corrective action has been taken. Some further expansion of the travel allowance will be required, however, to deal with the suggestions above for meetings of investigators and advisors on particular scientific areas and for attendance of NASA biological and medical staff at scientific meetings (see section below on Professional Personnel). Additional travel funds are also needed for improved monitoring of contracts by NASA management staff.

Professional Personnel

Positive steps should be taken to enable NASA medical/biological staff to maintain professional competence and to attract high quality, young, biomedical professionals. The following activities should be encouraged and supported: postdoctoral training (in selected cases), university affiliations, professional meeting attendance, research productivity and publications, and visits to other laboratories.

Because of the uniqueness of the space orientation of their work, the relative physical isolation of the Centers, and the relatively small numbers of biomedical professionals in NASA, there is a distinct tendency for them to become professionally isolated from their peers in their respective fields. The quality of what these scientists produce for NASA will be enhanced by positive efforts to keep them abreast of the constantly improving and expanding expertise in their fields.

Position "Ceilings"

Despite "ceilings" on employment in all departments and agencies of the Government which must be extended downward to every part of any agency, NASA management should give special attention to Life Sciences in respect to employment ceilings. Attention must be given to maintaining critical mass; any further reductions must be avoided.

The present number of NASA life scientists appears to be marginally adequate in most areas, but some strengthening will very likely be needed in selected areas as Shuttle/Spacelab demands increase. The question of inadequacy of secretarial and other support personnel merits attention as a deterrent to the efficient use of the professional staff.

Graduate Education

A vigorous mechanism must be developed to support graduate educational programs in aerospace medicine and, where necessary, in other space-oriented Life Sciences disciplines.

As a consequence of recent socioeconomic trends which have led to reduced and discontinued support of civilian training programs in the field of aerospace medicine, certification of this specialty by civilian professional associations is currently in jeopardy. This loss of a source of appropriately-trained, bright young professionals and of status as a certified medical specialty will clearly decrease the future capacity of the NASA Life Sciences to deal effectively with its responsibilities in both aviation and space. The Agency should be alert to the development of similar threats to the future supply of properly trained professional specialists in other allied fields and be prepared to take appropriate and timely preventive action.

Medical Sciences

Long-Term Support

The Life Sciences Advisory Committee recommends that NASA be prepared to sustain support of long-term medical research programs in the area where the space environment affects physiological function, and thus may disable space travelers. This support should continue during those interim periods when missions are being planned or NASA is in the process of altering its mission goals.

Crash programs of biological and biomedical research are not only extremely expensive, they are prone to failure. Such programs too frequently result in the application of harmful rather than helpful solutions. Suspension or severe curtailment of biomedical research can be recommended only if human travel in space is deemed to have no role in the future missions of NASA.

Problem Areas for Long-Term Flights

Issues related to insuring the survival, good health, and adequate performance of man on long-term space flights should receive highest priority. These issues include:

a. Determination of the mechanisms of bone and muscle deterioration during exposure to weightlessness and the development of countermeasures to prevent this deterioration. Increased emphasis should be placed on factors influencing muscle integrity in weightlessness.

The changes in bone and muscle observed during short-duration space flights and Skylab promise to be most disabling on long-duration space flights. One finding in rats (Kosmos) suggests that new bone formation is slowed in space despite provision of artificial gravity; this unpredicted result shows that a great deal remains to be learned about the mechanisms of bone changes in *weightless conditions. At present, our knowledge about the mechanism of muscle loss in weightlessness is even less than that about bone changes. Studies of several types of countermeasures are being pursued.*

b. Better understanding is required of the integrative mechanisms that influence the risk of shock, unconsciousness, and impaired capacity of the cardiovascular reflexes necessary to maintain upright posture upon return to planetary gravitational influences from conditions of weightlessness. Better countermeasures and methods of selection should be developed.

The changes in cardiovascular function, fluid/electrolyte balance, and blood constituents appear to be the consequences of the body's successful adaptation to weightlessness. These changes probably facilitate healthy physiologic adaptation and successful performance in space. Having developed this adaptation to weightlessness, re-entry into Earth's or another planet's gravity carries increased risk of unconsciousness and impairment of the capacity to perform in an upright posture. This appears to be due to changes in cardiovascular reflexes, in the dynamics of fluid/electrolyte controls, and in the loss of circulating blood volume. Anti-G suits provide one countermeasure, but also increase dependence on complex devices. Better selection, training (on ground and in space), use of pre-reentry fluid replacement, artificial gravity, and pharmacologic agents all provide approaches to dealing with these problems more successfully. Certain other changes, secondary to fluid and blood shifts in space (e.g., possible increased pressure in cardiopulmonary arteries), deserve serious attention, although they do not seem to be an immediate threat. Some of the seemingly benign changes associated with weightlessness may prove to be serious problems as longer missions are attempted.

c. Assessment of the hazards associated with exposure of non-replicating tissue to radiation by particles with high atomic weight (HZE) and development of methods for preventing exposure to such particles is required.

Risk to non-replicating tissue from HZE particle exposure is a unique concern of NASA. Flight experiments will be required in the future. The development of methods to achieve terrestrial exposure of appropriate biological targets to HZE particles at realistic dosages, using available specialized accelerators, is necessary for significant advances in this area. Data from this area of work will be necessary to determine the degree of health threat represented by HZE particles and the nature of countermeasures required.

d. Issues related to the performance aspects of long-term manned space flight that influence the maintenance of the physiological and psychological integrity of the crew require continuing investigation, as well as continuing and more explicit coordination with ongoing work on aeronautics performance and safety.

The nature of crew selection, organization, and training, as well as the provision of long-term habitability of the spacecraft or station, will ultimately determine the complexity, length, and productiveness of long-term space missions. Performance studies explicitly address matters relevant to these factors.

Problem for Short Flights; Space Motion Sickness

In the near future, high priority should be assigned to the study, prevention, and treatment of space motion sickness. Several approaches to space motion sickness should be pursued:

a. Fundamental research in mechanisms which cause space motion sickness.

b. Development of special novel training procedures to suppress symptoms. (Preconditioning with aerobatic flight has not worked.)

c. Development and use of pharmacologic agents to suppress symptoms and evaluation of the physiological cost of these agents as they affect other vital functions, i.e., cardiovascular, muscular coordination, consciousness, etc.

d. Development of selection standards to exclude subjects likely to get sick in space.

Space motion sickness is likely to disrupt performance and well-being during the first two to four days of a flight and be a significant problem during the short-term flights of the Shuttle era. Increased fundamental understanding of the mechanism of this problem is necessary for countermeasure design. A combination of countermeasures will probably be required to deal with the problem. Although non-selection of individuals very sensitive to motion sickness is clearly prudent, a radical improvement in selection efficiency seems unlikely in the near future.

Integration of Research Efforts

Integration of research efforts across RTOP areas should be continued and increased to include:

a. Collaborative utilization of joint terrestrial models (e.g., chronic bed rest) to examine an array of dependent variables (e.g., calcium loss, muscle loss, cardiac deconditioning, changes in fluid and electrolyte distribution).

b. Increased sharing of results in topically organized conferences which encourage exchange between Principal Investigators and RTOP technical monitors. One goal of such conferences should be to establish and refine animal models which may be used to solve health-related problems.

c. Annual meeting of all RTOP technical monitors, principal investigators, and consultants in programs of research in the medical sciences to:

   (1) Increase program integration

   (2) Encourage collaborative work between NASA laboratories and extramural personnel

   (3) Recertify the relevance of all elements in the RTOP mission

   (4) Update and modify research strategies.

These efforts directed toward increased programmatic integration should explicitly operate to decrease any fragmentation of efforts due to the tendency of NASA Centers to compete with each other at the expense of collaborative efforts. The Committee recognizes that competition may encourage and motivate, but it can also fragment effort. The Life Sciences Directorate has demonstrated its recognition of this problem. Recently some improvement on collaborative use of resources has been achieved across laboratories. This Committee wishes to encourage this trend while recognizing that some fraternal competition between Centers is healthy.

Fundamental Medical Science

Management should continue support of programs which address fundamental medical science issues in an innovative way.

One problem inherent in NASA Life Sciences Medical Research Programs is that emphasis on concrete operational problems and the need for quick results may stultify creative, innovative efforts that provide basic scientific breakthroughs of greater long-term worth.

Gravitational Biology

Studies of gravitational biologic issues that facilitate work in the Medical Sciences should receive priority consideration.

A sizable portion of NASA Medical Science Research Programs relate to the effects of gravity or its absence upon physiological systems. Studies in the Medical Sciences will contribute to the field of gravitational biology and will draw data from this area of study as it applies to the impact of gravity upon mammalian adaptation.

Biomedical Systems and Operations

Susceptibility or Predisposition to Flight Effects

Current studies directed toward determining sex and age differences in susceptibility to space flight effects warrant continuing emphasis. The detection and quantitation of latent coronary disease and evaluation of attendant risk factors and their control should receive close attention in the medical selection program. Newly evolving techniques, including those which might develop in the pre-flight detection of disease program, should be examined for their applicability to the detection of other forms of latent pathology.

The broadening composition of flight crews to include personnel of both sexes and wider age ranges makes it necessary to establish sex and age differences on a scientific basis with respect to susceptibilities to the effects of space flight. Latent pathology is primarily an age-related factor, and *latent coronary heart disease is emphasized on the basis of its great prevalence and potentially severe consequences.*

The recognition and quantitation of predispositions to the orthostatic, musculoskeletal, hematological, and fluid and electrolyte changes of space flight, and the development of appropriate measurable indices should receive continuing attention.

While these changes are, for the most part, considered adaptive to the weightless state, they are at the same time "de-adaptive" to 1-G and reentry-G tolerance. Tendencies of crew candidates to respond in an exaggerated manner to these effects must be detected, measured, and either corrected or regarded as disqualifying.

Role of Physical Exercise

The role of physical exercise in flight, as well as pre-flight, remains to be more clearly defined for its alleged salubrious effects. Controlled in-flight experiments should be designed to determine the precise effects of exercise on orthostatic, musculoskeletal, and fluid and electrolyte changes. Similarly, pre-flight exercise protocols should be carefully evaluated for both positive and negative effects on in-flight and post-flight circulatory, musculoskeletal, and fluid and electrolyte responses.

The fact that exercise improves a sense of well being in flight crews is widely accepted, but at the present time, there is too little evidence to indicate whether or not it exerts any beneficial effect on flight-induced physiological changes. There is some evidence to suggest that pre-flight exercise might have some adverse effect on in-flight circulatory and musculoskeletal responses by essentially exaggerating the losses because of heightened pre-flight blood volume, bone mineral, and muscle mass levels. These uncertainties remain to be resolved.

Integration of Operational and Research Activities

An effort should be made to assure the integration of medical operational and medical research activities so that the research is properly directed to the operational problems, and research findings may be quickly tested and utilized in the operational environment.

Reliability and Cost/Benefit Analyses

Consideration should be given to the addition of efforts to provide reliability analyses, such as fault trees and cost-benefit analyses, to the studies of physiological design requirements for life support systems.

Although these important aspects of life support system design are not in evidence from the material provided for review, they should not be neglected.

Teleoperator Technology

The advancement of teleoperator technology should be regarded and programmed as a legitimate field of scientific research within itself and not simply tied to specific operational requirements. Because man is so intimately integrated in the loop, it properly falls within the purview of the Life Sciences. Since teleoperator technology is inherently a multidisciplinary effort involving engineering, several specialty fields of medicine and psychology, and computer technology, it requires a correspondingly integrated approach.

Remote communications and control involve, in effect, an extension of man's nervous system, and can ultimately be designed to convey a real sense of presence at the remote location. Understanding what teleoperators can and cannot do has been hampered because such developments in the past have been oriented to specific operational requirements, with funds allocated accordingly.

Man-Machine Engineering

Continuing research in man-machine engineering requirements is warranted; NASA's sustained research program to improve space suits and extravehicular systems is essential to any future advancement of man in space.

While the state-of-the-art in both of these areas is adequate for Shuttle, future requirements may be expected to be more complex with respect to metabolic demands, habitability, and man-machine integration, due to the probability and expectation of heavy work achievement in space.

People vs. Computers

We recommend that a small multidisciplinary ad hoc task group be constituted to address and make recommendations on a newly emerging, highly complex, and increasingly important area which we refer to in the text as "People vs. Computers." Specific questions to be resolved are:

(1) What underlying scientific discipline needs to be developed in man-machine interaction, what aspects of such disciplines should NASA be responsible for developing, and what aspects should be left to other agencies? Where are the gaps in current NASA efforts to develop such discipline, and where are the strengths?

(2) What NASA projects or activities in this area would benefit from closer coupling, and what projects or activities must necessarily be left independent of one another?

(3) What administrative arrangements can best serve to integrate NASA life science and engineering efforts to achieve these ends?

(For rationale, see pages 15 through 17 in text.)

Regenerative Life Support Systems

Efforts should be made to develop systems for partially closed life support, including demonstration equipment, for the widest range of missions to achieve key regeneration functions. Use of long-term Space Shuttle and Spacelab missions should be encouraged as an appropriate test laboratory for study of the effects of weightlessness on candidate regenerative biological processes for life support system closure.

Food Technology

Greater emphasis should be placed on food technology for manned space flight, to include nutritional requirements, nutritional equivalency of different food sources, physiological and psychological acceptability of non-conventional food sources, etc.

As missions are extended, launch weight, power, and cost efficiencies favor progressive closure of life support systems. For long-term space habitation, such as lunar habitat or space settlement, the most efficient system will be a regenerative, self-perpetuating, and independent system which provides the atmospheric, food, water, and waste management requirements to support man permanently. The long lead time needed to create this capability forms the basis for the two recommendations above, since the state of knowledge of this field is presently inadequate even for the accurate planning of such missions.

Aviation Medicine and Safety

Overall research in aviation medicine and safety should be expanded in coordination and conjunction with the DoD and FAA with the aim of clarifying the advantages and disadvantages of further automation, the relative roles of man and computer, the ability of man to detect, diagnose, and remedy sudden failures in automatic systems, and the relationships between pilot error and simulator training.

Pilot workload is continuing to increase with increasing air traffic, increasing demands for all-weather operations, and increasing instrumentation and automation. There is evidence that pilots may be exposed to an excessive number of warning systems and that interfaces between man and onboard automated devices may be inequitably distributed for maximum safety. The high incidence of pilot error in aircraft accidents (60 to 70 percent) and aircraft fatalities (90 percent) emphasize the need and importance of this research. It affects the safety of the entire future generation of air travelers.

Biological Sciences

Space Biology

The program in Space Biology should be viewed as a demonstration of the possible benefits of biological experimentation in space.

This recommendation is consistent with the general goal of the Agency and with the fact that a broad research program in, for example, developmental biology, is inappropriate within NASA. It follows that the planning of these activities requires special care, with the scope of the research topics being carefully specified, and with the objective chosen deemed appropriate to the goal of demonstrating the possible benefits of experimentation in space. A carefully structured program in Gravitational Biology can be fully consistent with this policy.

Planetary Biology

Funding of the Planetary Biology program should be improved, with developments following the possibilities outlined in Appendix C.

The Planetary Biology program occupies a position of special public and scientific visibility and interest. Although it has always provided an important positive force in the operations of the Agency, the funding in Planetary Biology has recently been decreased. This erosion of support comes at just the time that planetary biological questions are taking a more advanced and general tone and could aid more directly in explaining the need for continued exploration of the solar system.

Planetary Protection

Special attention should be given to the problems associated with sample return missions.

Many of the concerns being raised in connection with the biological risks of sample return missions can be dealt with adequately only by substantial efforts in research and development. Solutions to some of the problems can be expected only after lengthy periods of development. Unless adequate attention is given to these matters now, the timely accomplishment of these missions may be precluded.

Environmental Effects

Activities regarding the real and potential environmental effects of NASA programs should be carefully reviewed and controlled.

Funding and manpower for these efforts should be supplied by the "client programs" (this is already true in part – the Shuttle program does fund the environmental studies at Kennedy Space

Center). Environmental studies which cannot be supported in this way, for example, the studies presently underway regarding the biological effects of ultraviolet radiation, should be viewed with extreme caution. In particular, the motivation for and objectives of such projects should be explicitly defined, and care should be taken that the responsibilities and activities of other agencies are not duplicated.

Payloads and Applications

The activities in this group of NASA programs are, in general, very practical efforts supporting the more research-directed programs. Each has a special feature of importance to NASA. Although it is somewhat difficult to assign relative priorities within this group, the activity of most pressing importance at the present time is that which supports the flight experiments of the upcoming Shuttle-Spacelab flights.

Life Sciences Flight Experiments Program

Life Sciences experiments proposed for Spacelab must be given intensive, careful peer review to select those of highest quality; where appropriate, approved investigators should be organized into collaborative teams.

Since the number of Life Sciences applications for flight experiments is high and the quality of those thus far appraised is also apparently high, this means that there is an extraordinary opportunity to increase greatly the knowledge of space biology and physiology. Logical groupings or pairings of investigators with the best ideas and best quality on the record of past research experience and productivity is the way to take maximal advantage of this unique set of opportunities.

In this process of receiving and reviewing applications for flight experiments, the staff should be sure that there is correlation between payloads projects and SR&T projects. All investigators currently receiving SR&T support should have the opportunity to apply for possible inclusion in Spacelab studies, on the natural assumption that knowledge learned in SR&T projects will be applicable and useful in Spacelab studies, and that Spacelab can and should be used as a test platform for SR&T-derived hypotheses. Conversely, care should be taken not to approve applications for payloads support previously disapproved for SR&T funding, unless significant changes (improvements) have been made.

Flight Support Facilities

High priority should be given to design and development of flight support facilities for both plant and animal research, with flexibility to provide for the varying features of many different experiments on flights of different durations and different emphases.

The Spacelab flights, with their attendant support laboratory facilities, represent the first opportunity to use weightlessness as an environment to study the requirements for gravity stimulus for normal growth and morphogenesis of plants and animals and to investigate the mechanisms of gravity stimuli and receptors. These flights also represent opportunities to investigate previously observed space phenomena (space motion sickness, bone demineralization, etc.).

Vestibular Research

Support should be provided to the VFR experiment in early flights of the Spacelab series. However, because of its expense, it should be followed closely and peer-reviewed frequently during the course of its development to assure appropriate cost-benefit.

The VFR flight experiment addresses a major question of the mechanism by which vertebrates sense and adapt to gravity. It rests on a reasonably good scientific basis. The results may guide future studies of mammalian vestibular function and thereby ultimately contribute to solving the problem of space sickness.

Biomedical Technology Applications

Instruments and techniques developed for use in medical research on space flights should be reviewed constantly for possible application to diagnostic and therapeutic clinical medicine and to medical research on Earth.

Because of the possibility that projects in this program will provide specific, unusual and useful spin-offs of space technology which would reflect favorably on NASA flight programs, this objective should be pursued.

Steps should be taken to assure that Technology Utilization and Space Applications benefits are adequately publicized to the voters and taxpayers.

The public does not seem to be sufficiently aware of these NASA efforts, nor of the successful contributions to the welfare of "the man on the street" which they have achieved.

PERSPECTIVES

The National Aeronautics and Space Act of 1958 defined eight objectives for the agency it created. The recently developed five-year plan has restated these objectives in more specific form. Three of these objectives are especially relevant to the Life Sciences and provide a context within which the present programs can be evaluated.

The goals of the Agency include:

3. Development and demonstration of techniques and systems that will contribute to human well being by exploiting the characteristics of space and space flight and transfer of technology to, provision of operational assistance to, and encouragement of other organizations, both public and private, in applying space opportunities for the benefit of humanity.

5. Expansion of humanity's understanding of the origin, development, and nature of the solar system and the universe; of the physical laws that govern the universe; and of the origin and distribution of life in the universe.

6. Study and development of more effective capabilities for humans to live, work, and explore in space for extended periods of time.

To be more explicit, the program in Space Biology and many of the Payloads and Applications programs can be associated with the third objective; the program in Planetary Biology with the fifth objective; and all Medical Sciences and related programs with the sixth objective. Notwithstanding these major associations, the programs involved with the various aspects of man-machine interactions and with the development of advanced life support systems make contributions to the first and second Agency objectives (advancement of aeronautical science and technology, and advancement of space technology).

Consideration of this range of overall Agency objectives is instructive. It indicates clearly that the very broad range of topics within the Life Sciences programs originates in the *needs of the Agency*. While other program areas may have an intellectual unity that appears attractive to anyone who has tried to comprehend all the programs within the Life Sciences, few, if any, are called upon to make contributions to so many different objectives.

The preceding discussion provides a means for assessing priorities within the Life Sciences. The "man in space" and "origin and distribution of life" objectives are not shared with any other area. The success or failure of the Agency in these areas will depend entirely on the programs in the medical sciences and in planetary biology. Accordingly, these can be regarded as forming the core of the Life Sciences. Care should be taken that these areas are strengthened, including the development of new initiatives. If the new initiatives are chosen wisely, and the existing central programs are funded adequately, success and progress in these central activities are likely.

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There are programs within the Life Sciences Directorate which are aimed at collaborating with other parts of NASA. We recognize at least two different types, those which require primarily a liaison function, and those which require more extensive collaboration. Among the former is the Technology Utilization Program, which, in the Life Sciences area, serves an essential and well-accepted need to transfer medical and bioscience technology into the civilian industrial sector. Unfortunately, funds and personnel time to implement this transfer compete directly with those available for basic life sciences and for support of NASA missions. As the required activity goes beyond scientific liaison and becomes promotional, it is questioned whether such activity makes most effective use of Life Sciences personnel.

A second type of activity requiring collaboration with other parts of NASA concerns the scientific aspects of man-machine integration in such areas as aircraft piloting and traffic control, space mission control, and control of teleoperators for construction and exploration. Effective solution of these problems requires the development of an applied scientific discipline. What discipline now exists is inadequate to the task. The required effort, which is fundamentally *interdisciplinary*, cannot be passed off to *either* the engineers *or* the life scientists for administrative convenience, nor can it be accomplished by half-hearted programs independently conducted by engineering or life sciences groups. Integrated team efforts of critical mass are essential here, and the role of the Life Sciences is significant insofar as the most complex and least understood problems here are in the Life Sciences. In view of the fragmentation which now exists in doing such man-machine integration and in developing a scientific basis for same, we feel that this area warrants special attention.

Finally, there are areas in which the Directorate provides services to various disciplines. It is likely that the space environment can be useful in studies of fundamental biology, particularly developmental biology, but leadership for such development should come from within the discipline to be served and a broad program of research on the problems in developmental biology, for example, would be inappropriate to NASA. The role of NASA in this and similar activities should be to demonstrate the possibilities of space experimentation for which continuing support could come from other agencies.

Primarily concerned with human space flight and with life in the cosmos, the Life Sciences in NASA occupy a position of central importance in the Agency's most fundamental goals. Given adequate focus and funding, there is every reason to believe that very significant progress can be made in these areas. In addition to their practical and scientific value, these programs are valuable to the Agency for the public interest and support which they elicit. Accordingly, care must be taken that they are well done.

APPENDIX A

MEDICAL SCIENCES

MEDICAL SCIENCES

Bone and Muscle

Rationale

Maintenance of the functional integrity of bone and muscle is the complex consequence of evolutionary selection arising from the constant influence of Earth's gravity. When man travels under weightless (free fall) conditions in space, a striking effect of the lack of gravity is the loss of bone and muscle. This effect is of greater importance as the length of time in weightlessness increases. The loss of such tissue is similar to that which occurs when men or animals are immobilized (or put at bed rest) for prolonged periods. The basic rationale of biomedical research supported by NASA concerning bone and muscle is:

(A) To document the nature and degree of bone and muscle changes in space in terms of their potential for disrupting space missions and producing injury in space crews;

(B) To define the mechanisms which produce these changes by doing relevant experiments in space as well as by developing relevant terrestrial models for the sorts of bone and muscle changes which occur in space;

(C) To develop and document the effectiveness of various countermeasures to prevent untoward consequences of bone and muscle deterioration; and

(D) To contribute fundamental information to gravitational biology. (Bone and muscle tissues are primary specializations within the animal organism in their response to the force of gravity.)

Many of the phenomena that relate to changes in bone and muscle will also produce changes in fluids and electrolytes. (See the section on this subject.)

The original basis for predicting that space flight, involving a long period of weightlessness, would likely have serious consequences for bone and muscle function lay in previously observed functional derangements in long-duration bed rest or immobilization. Since long-term weightlessness cannot be duplicated on Earth, the nearest analogy likely to be valid was thought to be inactive bed rest. Water immersion is not practical, because it cannot be continued long enough to be a useful test situation for effects on bone and muscle.

The literature on disuse atrophy of bone, through 1959, was reviewed by Whedon, and the various experimental studies of physical inactivity and immobilization in both animals and man, through 1967, were summarized and analyzed with respect to various influential factors by Birge and Whedon.[1, 2]

Among the numerous studies of bed rest in humans over the past 30 years, two can be selected as particularly pertinent for predicting that the weightlessness of space flight would bring about significant alterations in mineral and nitrogen metabolism. The earliest was that of Deitrick et al. in 1948.[3] Immobilization of four healthy young men in body casts for six to seven weeks led to marked increases in urinary calcium and significantly negative calcium balances. There were related losses of nitrogen and phosphorus, reflective of muscle atrophy. Several subsequent bedrest studies of normal subjects confirmed these substantial metabolic derangements. The longest observation of normal human subjects in bed (Donaldson, Hulley, and associates, 1970[4]) showed that although the elevated urinary calcium subsided partially during the third and fourth months of bed rest, it nevertheless remained significantly higher than control levels as long as bed rest continued (seven months) and did not fall to normal until the subjects were back on their feet.

Although preliminary short-term observations of calcium and phosphorus loss in space were made during Gemini VII in 1965[5], full corroboration of the predictions from bed rest of significant metabolic disturbances in space came during the Skylab program. A metabolic study of the effects of space flight on various chemical elements, particularly those with special relevance to the musculoskeletal system, was carried out on the nine astronauts who participated in the three Skylab flights of 28, 59, and 84 day duration in 1973-74. For cooperating crewmen, the study required extremely constant dietary intake, continuous 24-hour urine collection and fecal collection for 21 to 31 days before each flight, throughout each flight, and for 17 to 18 days postflight.[6]

During space flight, increases in urinary calcium and changes in calcium balance were similar in degree to those found in bedrest immobilization. These losses of calcium measured by the metabolic balance technique were confirmed by bone densitometry measurements of the os calcis. The rate of loss was 0.3 to 0.5 percent of total body calcium per month, a figure made more pertinent by the fact that, based on previous studies, the loss of minerals is not uniformly distributed, but is concentrated in the bones of the lower extremities. Similarity to bed rest in pattern of urinary calcium increases and of total calcium shifts suggested that these calcium losses would continue for a very long time. Significant losses of nitrogen and phosphorus also occurred, associated with observed reduction in muscle tissue. Both mineral and muscle losses occurred despite vigorous exercise regimens in flight.

The presumed significance of these space tested metabolic results is that the loss of bone could, after flights of sufficient duration, lead to weakening of bone structure and render bones susceptible to fracture. Although in-flight trauma of sufficient degree to cause fracture is difficult to imagine, upon return to Earth, or even while working on the surface of a sizable planet, a broken ankle is a distinct prospect after a one to one and one-half year flight.

The significance of muscle loss, as observed in the Skylab studies, is more difficult to assess. The astronauts developed evident leg muscle "flabbiness" and decreases in size, while the nitrogen balance showed a 4.0 gm per day negative shift, certainly due to muscle breakdown. In space flight and in six to seven weeks of bed rest, there was a significant decrease in muscle strength. Although it is difficult to be certain of the extent to which muscle weakness might gradually proceed in long flights, it seems possible that after a flight of many months some critical maneuver in flight, or more likely, some physical task on the surface of a planet, could be compromised as the result of derangement in muscle function.

Status

The situation with respect to possible space flight effects on both bone and muscle is that the pattern and degree of disturbances, and their continuing nature, are sufficiently clear that serious notice must be taken. If long duration (one-plus years) space flights are a real prospect, then action must be taken to obtain a set of measures, procedures, or regimens which will prevent these deleterious changes and protect the musculoskeletal system for effective functioning.

The intrinsic pathophysiological mechanisms underlining these derangements are understood only in primitive form. To whatever extent that these mechanisms are elucidated by research, such knowledge should facilitate the development of useful protective countermeasures.

With respect to bone, long-term metabolic observations of paralytic poliomyelitis suggest that as long as the influence of disuse is present, bone loss will continue unabated until osteoporosis becomes clearly evident; then the rate of loss will finally begin gradually to subside. Such losses amount to approximately five to eight percent of total body calcium, but because of the geographic differential of bone loss (in the lower extremities mainly, with intermediate loss in the spine, and hardly any in the upper extremities), the local loss of mineral in a tibial bone end would be ten to twenty percent at a minimum. This is a degree of bone/mineral loss which renders bone predisposed to fracture.

The question of risk of urinary tract stone formation from increased amounts of calcium in the urine is often raised, but present knowledge in this area provides assurance that such an event can almost certainly be prevented by maintenance of adequate urinary volume from abundant fluid intake.

With respect to muscle, the situation is less distinct. In most, if not all, bedrest studies, although the loss of nitrogen (mainly from muscle) continued as long as bed rest continued, it subsided in degree to levels which were of questionable physiological significance. In the Skylab flight studies, however, the degree of nitrogen loss in the longest flight (84 days) had hardly subsided to any extent by the end of the flight. Another aspect of the nitrogen metabolism studies in space is difficult to interpret: the highly positive balance of nitrogen during the control phase. Although the increase in urinary nitrogen excretion during the flight was about 4 gm per day, the actual negative nitrogen balance during flight was little more than 1 gm per day. A continuous collection measurement or dietary intake error are possible explanations. In any case, the large shift in excretion during flight is of greater significance than the level of measured "balance."

With derangement of bone/mineral and muscle/nitrogen function of these degrees, the necessity for protective or corrective measures (for long duration flights) is evident. During the second and third Skylab flights, astronauts, on their own, tried the most obvious "countermeasure" – physical exercise. Even though the forms of exercise were quite vigorous, they obviously provided little, if any, protective effect since the nitrogen and calcium metabolic changes were so sizable. Various kinds of exercise in controlled bedrest studies have also failed to stem the loss of these key elements. Some other counter regimen or measures must be devised.

Ongoing Effort

Beyond the space flight studies mentioned previously, NASA has exerted efforts to obtain more research information on the problems of bone and muscle function by conduct and support of a variety of projects which may be summarized as follows:

1. Contract support of long-term bedrest studies on normal human volunteer subjects, at USPHS Hospital, San Francisco, to determine the mechanisms underlying the effects of inactivity and, mainly, to develop and test various countermeasure procedures and regimens.
2. Conduct of three studies related to the effects of bed rest/inactivity at NASA-JSC, Houston, Texas.
3. Conduct of ten studies related to effects of bed rest/inactivity at NASA-Ames, Mountain View, California.
4. Support of nine projects mainly for the development of measurement techniques at universities and research centers.

A listing and, where pertinent, a brief description of these studies follows:

1. The set of studies with probably the most immediate relevance to bone/muscle problems has been conducted at USPHS Hospital, San Francisco, beginning in 1968. In a continuing effort to find an effective protective measure, the investigators have tried to suppress increases in calcium and nitrogen excretion by bed rest in tests of (A) horizontal exercise, (B) compression of the body from shoulders to feet, in static mode and intermittently, (C) salmon calcitonin, a hormone which influences calcium retention, (D) increased phosphate intake, (E) increased calcium and phosphate intake, (F) continuous and cyclic lower body negative pressure, (G) added diphosphonate (EHDP) at two dosage levels, and (H) repetitious impact loading to the heels at two load levels. To date, effects have been

negative except for uncertain and variable indications of protection from the higher dosage level of EHDP and from calcium and phosphate supplements.

2. *NASA–JSC Studies*

A. Improvement in assays for parathyroid hormone, vitamin D metabolites and calcitonin, development of a more sensitive isotopic methodology to measure bone resorption, study of interrelationships of glucocorticoid expression, intestinal absorption of calcium and vitamin D metabolism.

B. Studies of usefulness of 3-methyl-histidine and of various collagen breakdown products as indicators of muscle mass and collagen breakdown.

3. *NASA Ames Studies*

A. Studies Related to Bone

Five projects are concerned with various aspects of disturbances of bone metabolism and function related to altered gravity, including (1) effects of restraint on monkeys and the influence on their disuse osteoporosis of high and low calcium diets, (2) mechanisms of calcium homeostasis in altered gravity states (endocrine, glucocorticoid and vitamin D metabolism in restrained rats), (3) development of non-invasive measurement technique for bone elasticity and stiffness and studies of monkeys and humans for relationships of bone elasticity to bone strength, (4) better definition of the disturbance of collagen metabolism in disuse atrophy by improvement in assay for alpha-hydroxy-glutamic acid and studies thereof in rats with disuse atrophy of various kinds, and (5) role of mechanisms of altered gravity states on growth and development of muscle and bone (chronic centrifugation of dogs).

B. Studies Related to Muscle

Projects concerned with alterations in muscle metabolism in hypodynamic states include: (1) proteolysis in tissue atrophy (definition of proteolytic enzymes, pathways and regulatory mechanisms of muscle in disuse atrophy), (2) relationship of growth factors to disuse atrophy in muscle and other tissues (effects of purified growth hormone on muscle and relationships of growth hormones to other growth factors), (3) muscle protein degradation with focus on glucose-alanine cycle in relation to endocrine changes and effects on branched-chain amino acids, (4) types of protein lost and endocrine relationships in muscle atrophy in animals, and (5) development of more sensitive assays for bio-active and immuno-active growth hormone.

4. *University Sponsored Studies*

A. Bone Mineral/Mass Measurement

The two projects in this area are concerned with (1) development of gamma ray computer tomography for determining small changes in trabecular bone, and (2) development of dual photon absorptiometry and multi-wire proportional counters for more precise measurement of bone mineral changes in trabecular bone and of fluid shifts.

B. Body Composition Measurement

One of the two projects in this area involves two techniques, both using radioactive tracers to determine changes in regional (leg or arm) mass of bone and muscle. The other project is for modification of the biostereometric camera technique to assess fluid shifts and other body volume changes in response to weightlessness.

C. Modification or Prevention of Bone Mineral Loss by Application of Electrical Techniques

The first project in this area is for investigation of the usefulness of non-invasive application of electromagnetic fields for prevention of bone loss associated with weightlessness, thus far shown to be useful in experimental fracture healing in animals and in facilitation of healing of fractures with delayed union. The second project involves study of electrical stimulation and administration of anabolic hormones on experimental osteoporosis and fractures in animals.

D. Studies Related to Muscle

One of the two projects in this group has the purpose of obtaining a better understanding of the biochemical and physiological changes in various muscle fibers when disuse atrophy is produced and when recovery takes place. The aim of the other project is to determine the feasibility of the use of a considerable number of nonradioactive isotopes in the study of muscle metabolism and possible adaptation of such techniques to inflight studies of muscle.

Studies conducted or supported by other agencies or departments are not known to the Life Sciences Advisory Committee. As a start, a search could be made of the most likely agency, NIH, by putting an inquiry into the NIH Computer Retrieval of Information of Scientific Projects (CRISP) system for studies of this type currently supported by NIH grants.

Critical Questions

The critical questions with regard to bone and muscle seem to be the following:

1. Can the derangement of or deterioration in bone and muscle function associated with long-term weightlessness be protected against by suitable procedures or measures?
2. What are the bases or mechanisms for these derangements?
   - In Bone: Do absent direct physical stress, diminished muscle pull on periosteum, circulatory changes, hormonal changes favoring increased bone resorption, other factors not now recognized, or combinations of several factors contribute?
   - In Muscle: What are the factors which are responsible for or participate in disuse atrophy (diminished size and strength)?

Adequacy of Current NASA Program and Funding

The current NASA program system in this area is functioning adequately. However, there is an apparent lack of coordination between in-house studies of hypo-gravity states in animals (at Ames), of bed rest in humans for cardiovascular effects (ARC), and contract-supported bedrest studies of bone and muscle metabolism at the USPHS Hospital, San Francisco (monitored by JSC). These studies would likely benefit from a more coordinated organization of the scientists currently working on these problems. By comparison with the current laissez-faire system, a regular system of exchange of developing research results might facilitate or speed up progress, result in development or revelation of critical specific research questions and ideas, and potentially lead to a considerably more productive program. Such exchange through meetings or conferences should include consultants and investigators in the field who are supported by other agencies in order to obtain the most complete and up-to-date information.

Funding and Priorities. The current funding level for this program area seems barely adequate. A gradual expansion, at least in proportion to the annual rise in inflation/cost-of-living, seems necessary. The NASA Life Sciences Directorate is cognizant of the importance of this area for astronaut function in long-duration flights and seems aware of the necessity for a continued research effort toward solution by the time such flights actually begin.

Projections

In the bone and muscle area, the bone-loss problem has received close attention as the subject of many projects. Substantial progress has been made in delineating the phenomenon and substantial effort is underway to deal with it. In contrast, the muscle/nitrogen-loss problem is just beginning to be appreciated and its understanding and management will require a substantial, essentially new effort. This problem should now be projected as having a very high priority in studies over the next several years.

In the bone/calcium problem studies, one would forecast (1) continued efforts to develop more precise and accurate methods to determine bone mass or mineral content, particularly for the regions (lower extremities) under greatest threat in weightlessness, including a method applicable to periodic use in flight; and (2) continued attention to preventive or protective procedures or regimens in all three currently prospective directions: physical, drugs/hormones, and dietary. In the latter direction, based on studies unrelated to bed rest, attention will certainly need to be given to dietary calcium/phosphorus ratios and the effect of high protein dietary intake in increasing calcium excretion in the urine. The latter result of high protein intake is mainly important in intensification of the calcium loss from bone but has some significance in increasing the potential for urinary tract stone formation.

Summary and Recommendations

Observation and study of the effects of space flight on the musculoskeletal system indicate that derangements occur of sufficient degree to signify potentially serious dysfunction in long-duration flights (many months). This system is under no significant threat in short flights (a few months), although the processes of calcium and nitrogen loss are manifested early. These losses are of sufficient magnitude, and their continuation sufficiently predictable, that the general recommendation is mandatory that studies continue to be conducted and supported for the purposes of understanding the phenomena and of developing protective or preventive measures.

Specific recommendations:

A. On scientific priorities – intensify studies related to the muscle protein/nitrogen loss in space/bedrest restraint, while continuing the effort to understand and prevent mineral loss.

B. On program activities – in relation to the general need to increase the input of expert investigators in universities and in other research centers outside NASA, and to intensify attention to the muscle/nitrogen loss problem:

(1) hold an annual meeting of a small number (approximately 12) of investigators in muscle physiology/metabolism and bone/calcium metabolism to review progress in the various projects in the research program on bone and muscle alterations and to make suggestions and recommendations on further research;

(2) hold periodic conferences/workshops of 30 to 40 scientists on particular subjects within the RTOP on Bone and Muscle; and

(3) include scientist-astronauts with biological and medical backgrounds in workshops and review meetings.

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Cardiovascular

Rationale

An initial unique impact of space flight on circulation occurs when the crew encounters the weightless state. Upon entering weightlessness, astronauts describe congestion of the head and neck. Measurements show a shift of blood from the legs to the upper part of the body. Blood volume is then reduced by excretion of fluid from the body. Thus, the weightlessness of space flight results in a series of changes in body fluid volume and circulatory reflexes. Within a few days of entering zero gravity a deconditioning occurs in the physiological processes or systems essential for maintaining adequate circulation and consciousness in the upright position in the 1 g environment. After experiencing this deconditioning, a man returning to full Earth gravity, on first standing up, experiences a pooling of blood in the legs, a period of rapid heart action, a fall in blood pressure (i.e., orthostatic hypotension), and, if the man is not made to lie down, a dimming of vision and a loss of consciousness.

These difficulties of blood pressure drop and loss of consciousness on reentry have, in the past, been corrected by antigravity measures (e.g., head-down posture, recumbent posture, or counter-pressure suit). In past missions, reentry has been in a recumbent posture (Gx), which minimizes gravitational stress on the crew. In Shuttle flights, pilots and crews may be subject to significant circulatory stress by making reentry in a sitting or upright position (Gz). The ability of the pilot and critical crewmembers to function during reentry and landing must be fully protected in this situation. The cardiovascular research program must address the issues necessary to provide such protection. Necessary work includes:

1. selection of individuals with a "natural" resistance to orthostatic stress.
2. preparation for reentry with appropriate technical support, e.g., anti-G garments.
3. minimization of circulatory stress of reentry into gravity through appropriate physiological strategies.

In addition, the cardiovascular program provides information of relevance to the gravitational biology of the heart and vessels of mammalia.

Status

Space flight appears to affect two aspects of cardiovascular function:

A. Peripheral vascular effects

B. Central effects.

A. Peripheral Vascular System Effects. Adaptation to weightlessness involves (1) redistribution of blood volume to the head and thoracic region (heart and great veins), (2) increased excretion of body fluids and decreased circulating blood volume, and (3) vulnerability to cardiovascular collapse on return to head-up posture in Earth's gravity. There is no longer any serious concern about the ability of astronauts to live and work in a weightless condition (except for a few hours or days of motion sickness discomfort on first entering free flight). The principal concerns now center on two issues: the maintenance of normal circulation during reentry into Earth's gravity and atmosphere when forces greater than 1 g may be encountered, and the recovery of normal cardiovascular function after return to Earth or other planetary environments.

Experience in Skylab has indicated that significant redistribution of extravascular and venous compartment fluid from lower body to upper body occurs as weightlessness is encountered; however, no clear evidence of diuresis and increased excretion of sodium ion has been documented. Pulmonary volume overload has been postulated as indicated by decreased vital capacity; other objective evidence (e.g., ECG evidence of right heart strain) is lacking. The current working concept suggests that venous and cardiac dynamic changes in response to a redistribution of body fluids are important to the adaptation to weightlessness. Readaptation of the cardiovascular system upon return to a gravity field involves cardiac and venous adjustment to hypovolemia which was the result of the previous adaptation to weightlessness. The response of heart rate to the application of negative pressure to the lower body appears to be the best indicator of orthostatic tolerance. In any case, at completion of the mission:

> *The experience of Skylab indicates that protection against orthostatic forces during the first few hours post flight not only serves to prevent orthostatic hypotension but may play an important role in cushioning the cardiovascular effects of return to gravity by preventing sudden large shifts of intravascular fluids to lower extremity vessels and extravascular tissues. Recumbency and the use of external pressure to counteract hydrostatic forces while in the upright position retard these readaptive changes which, if allowed to take place rapidly, can only accentuate the adverse effects of an inadequate circulatory blood volume (Biomedical Results from Skylab, 1977).*

B. Central Cardiovascular Effects. (1) The entire pattern of cardiovascular integration is modified by weightlessness. This may well be a "normal" response to fluid and electrolyte shifts produced by travel in space; however, the critical site or sites modified to produce this new integration are unknown. Among the systems modification thought to be responsible for this response are cardiac and thoracic mechanoreception interaction, changes in central nervous system activity, and modification of hormonal balance between the pituitary and the kidney. One consequence of these changes under conditions of weightlessness is greater sensitivity to lower body negative pressure. This manifests as a decreased capacity of the heart and vessels to respond to the stress of gravity.

(2) During space flight, a concern has been voiced about increased cardiac electrical instability. This is related to an alleged higher rate of cardiac arrhythmias and alterations in normal wave form. These changes have been observed in only a few isolated cases in the U.S. program and may be related to changes in fluids/electrolytes and vasoactive hormones (see section on Fluids and Electrolytes). In any case, some authorities doubt that cardiac electrical instability is a significantly greater risk in space.

Ongoing Effort

The primary approaches employed within the current program are:

A. Studies of fundamental cardiovascular changes and mechanisms associated with deconditioning.

B. Detection of latent cardiovascular disease.

C. Development of methods, devices, and procedures for prevention of untoward cardiovascular effects.

D. Development of advanced bioinstrumentation suitable for use in space.

A. Work concerning the documentation of the fundamental cardiovascular changes associated with deconditioning utilizes both animal and human models. Studies are undertaken of orthostatic tolerance following deconditioning after ground-based simulations of space travel. These procedures include identification of circulatory changes in dogs conditioned by exercise and then deconditioned by cage confinement. The standard comparisons are responses to blood volume and postural changes (tilt and lower body negative pressure [LBNP]) before and after deconditioning. Approximately six contracts are addressing these problems. Future plans include utilization of primates under a similar protocol.

One important type of simulation of space flight induced cardiovascular deconditioning is prolonged bed rest. This is a fundamental model for the analysis of adaptive mechanisms which produce a loss of orthostatic (postural) tolerance. Observations are made of the time course of changes in cardiac size, peripheral vascular compliance, and flow distribution. In two research projects, the effects of postural/gravitational stress upon these variables are studied in individuals who have lost their postural adaptation through chronic bed rest. Additional data in regard to the effects of bed rest are being generated in projects under *Fluid and Electrolyte Balance and Bone and Muscle*. Related to this effort, at least five different research projects are developing non-invasive instrumentation, and two projects are developing invasive instrumentation to improve our capacity to measure the consequences of cardiovascular changes. Taken as a whole, this work produces data which is combined with data obtained in studies for developing medical selection criteria to improve our understanding of mechanisms of deconditioning and to improve our standards for rationalized selection of crewmembers.

One study examines cellular changes under conditions of deconditioning. The emphasis is upon morphological and histological changes which occur after exposure to altered acceleration levels. The content and distribution of norepinephrine in cardiac muscle are being studied and the delay of changes documented.

Peripheral vascular measurements of arterial and venous mechanics are being pursued in three projects and ultrastructural changes are being followed in one. The measurements of combined factors concerning flow distribution, mechanical receptors, and cardiac output are being examined in approximately six separate research projects. One project concerns blood volume endocrine factors. Finally, two projects are attempting to develop systems models that provide a basis for predictive indices concerning cardiovascular function.

B. The detection of latent cardiovascular disease focuses its efforts on examining the patency and integrity of the coronary arteries and the presence of hypertensive vascular diseases. Cardiovascular conditioning in primate and canine models is studied in simulated exposure to gravitational stress (i.e., lower body negative pressure) and to various provocative cardiovascular demands. These models are evaluated to establish the values of the various stressor and physiologic measures in detecting known disease. Work within a total of eight projects relates to this effort. This work has direct relevance to crew selection.

C. The data from the foregoing work clearly attains its maximal significance when it is applied to developing methods, devices, and procedures for preventing untoward cardiovascular effects. Forces similar to those produced by a pogo-stick type exercise in flight are being applied to subjects lying passively in the supine position. Oxygen consumption and the distribution of forces over the body are being measured. If favorable effects can be produced in the supine subjects within acceptable force levels and durations, the same forces will be tested in bedrest subjects as a method of modifying deconditioning.

D. Prototype protective anti-G garments will be tested by static pressurization during bedrest and post-bedrest centrifugation. The gravity tolerance of test and control subjects will be compared. Subsequent tests will utilize oscillating pressures in bedrest subjects. The optimal suit configuration and pressure gradient will be determined by this work. Major parameters concerning deconditioning in space and at bed rest are being examined in an interactive computer-based model with a range of mechanical stimuli to find the conditions which provide the highest probability of successfully modifying deconditioning.

E. Development of advanced instrumentation suitable for use in space is being supported in several of the foregoing areas of research. Explicitly, this instrumentation includes emphasis on the non-invasive application to human studies. For example, ultrasound is being used to measure blood pressure, blood flow, and changes in local blood volume. Instrumentation for measuring pulse wave velocity, biopotentials and heart sounds (systolic time intervals), and volume shifts (plethysmography) are addressed in several project grants. Applications are under development, including ultrasonic systems, both directly-connected and telemetered, and multivariable telemetry systems for animal sizes ranging from rats through macaques.

Information processing of the high volume of analog data generated by long-term experiments and of complex waveforms, such as ultrasonic images, is also being supported.

Critical Questions

Priorities in research on cardiovascular adaptations to weightlessness and subsequent return to Earth gravity are:

1. Development of appropriate measures to counter the cardiovascular instability during reentry to 1 g (or to new forces which may exist in space facilities). This support during reentry should entail minimal interference with astronaut or specialist performance.
2. Pursuit of promising leads in research on cardiovascular responses to weightlessness and reentry. Does weightlessness cause significant pulmonary hypertension? Is there a change in venous compliance? Why did some astronauts have disturbances of cardiac rates and rhythms during space flight?
3. What is the relation between cardiovascular disturbances and the changes in blood volume and composition of body fluids observed during weightlessness? How can studies of cardiovascular function be correlated with endocrine-renal control of fluids and electrolytes to develop a holistic concept of physiological changes during weightlessness and reentry?

Adequacy of Current Effort

A. Program. The studies of deconditioning are generally appropriate, particularly in utilization of the bedrest model. Attempts to devise prototype garments and develop non-invasive instrumentation are appropriate to current understanding of the physiology of deconditioning. Focus on cardiovascular compensation during weightlessness, and its consequences to cardiopulmonary relationships, is an area where important questions remain and may require increased emphasis. Work toward detection of latent cardiovascular disease is at the state-of-the-art.

B. Funding. Funding, overall, is adequate; however, distribution does not reflect the above-suggested emphasis. The funding directed toward strategies to support readaptation during return to gravity is inadequate.

C. Priorities. The primary efforts should be directed toward:

1) Development of cardiovascular support strategy during reentry.
2) Continuing utilization of bedrest and primate models for a comprehensive cardiovascular fluid/electrolyte approach to understanding of adaptation.
3) Enhanced understanding of orthostatic balance, with major concern for the better understanding of venous compartment regulation.

Summary and Conclusions

Current research concerning the cardiovascular system performance and adaptation during space flight is concerned with (1) mechanisms of change during deconditioning during weightlessness, (2) development of technology to compensate inadequate cardiovascular performance, (3) development of non-invasive instrumentation approaches for data collection and parameter monitoring during space flight, and (4) detection of latent cardiovascular disease. During weightlessness, there is progressive cardiovascular adaptation, and judged by Skylab experience, the cardiovascular function is effective. Despite finite loss of reserve, cardiovascular capability is not limited to work performance. Lower volume of body fluid compartments and the smaller blood volume contribute to the variable cardiovascular response during adaptation to weightlessness. This reduction in volume is a problem during subsequent readaptation upon return to gravity. Efforts for determination of latent cardiac disease reflect current and standard methods for prediction by routine multiparameter analyses. It is recommended that greater emphasis be placed on development of techniques to assist cardiovascular readaptation during reentry to gravity fields. Such support methods should interfere minimally with operator work performance during reentry. The new appealing approach appropriately might involve conditioning with the lower body negative pressure regimen.

Fluids and Electrolytes

Rationale

In the absence of gravity, in weightlessness or at bed rest, blood and body fluid volumes are reduced within a few days. Bone and muscle composition losses continue throughout longer flights. Normal body composition is slowly restored when exposure to gravity is renewed. Research concerning the extent of these changes, their mechanisms, and countermeasures against them is necessary. This research is necessarily closely related to research conducted concerning changes of bone and muscle as well as cardiovascular function during space flight.

Status

As a crewman enters the weightless environment, his (or her) circulating blood volume and extracellular fluid shifts from the extremities and the lower abdomen and are redistributed toward the heart, the great vessels, and the head. This fluid redistribution initiates a compensatory loss of fluids and electrolytes. *The changes in water balance are believed to occur principally in the first one or two days of flight as they do in bed rest.* (See *Biomedical Results of Apollo*, 1975, p. 163.) Research accomplished in the space flight program has contributed greatly to our understanding of the problems of fluid and electrolyte balance associated with space flight (see *Biomedical Results of Apollo*, 1975, pp. 163-164; *Biomedical Results from Skylab*, 1977, pp. 208-215).

Continuous bed rest and water immersion are used to simulate the effects of weightlessness on fluid and electrolyte balance. The reduced blood volume which occurs in space and at bed rest results in increased risk of cardiovascular instability on renewed exposure to gravity and the erect position. In the case of the space traveler, this instability is manifest upon return to Earth or landing upon a sizable planet. Exposure to weightlessness over a longer duration causes further loss of potassium, calcium, magnesium, and electrolytes from the body. The consequences of long-term effects of weightlessness or bed rest on mineral and muscle balance are discussed at greater depth in the section of this Appendix titled Bone and Muscle.

The physiologic mechanisms which regulate fluid and electrolyte changes are not completely understood. Thus, the elaboration of critical factors which mediate changes under conditions of weightlessness are limited by the state-of-the-art. Nonetheless, a great deal is known in this critical area of physiology. The kidneys are the most prominent organ regulating normal body fluid volume and electrolytes. The kidney responds to variations in diet and environmental conditions and body demands. This is achieved by a variety of mechanisms. For example, sodium and water balance are affected by neural and humoral signals. Adrenal hormones (e.g., aldosterone, cortisol, epinephrine) affect the excretion of sodium and potassium, while the pituitary hormone, vasopressin, controls water excretion. These and other systems are finely tuned to maintain a normal volume and composition of body fluids during ordinary life on Earth. The effects of weightlessness initiate a new balance of these regulatory systems.

Hormonal changes were observed in analyses of blood and urine. Early in the flight, the elevation of epinephrine and norepinephrine indicated acute stress responses. Another sign of stress was the increase in cortisol in blood and urine specimens. The loss of salt and water was possibly responsible for an increase in secretion of renin by the kidney, and the generation of angiotensin. Plasma aldosterone was increased, and in turn, probably caused the observed potassium loss. When motion sickness limited water and food intake, the loss of body fluids and tissues was aggravated. Some of the potassium changes, as well as an increased excretion of nitrogen, reflect tissue loss, and loss of calcium and phosphorus from bones.

These changes are, for the most part, indicative of a successful adaptation by the body to the combined stress of weightlessness. Unfortunately, this adaptation by humans in space increases the risk of cardiovascular instability upon return to Earth. At present, the only countermeasures available that do provide substantial protection for crews are anti-gravity suits and devices. If properly used, such devices decrease the risk of transient loss of circulation to the brain with impairment of vision and loss of consciousness. It is unfortunate that the astronaut must be dependent on such a mechanical support system during the critical reentry phase following space flight. Such suits are at best a necessary additional encumbrance, and at worst liable to technical malfunction. Current technology does not permit the utilization of other countermeasures.

Ongoing Program

Given the complexity of the feedback systems that control fluid and electrolyte balance, the research programs in this area address multiple facets of fluid and electrolyte control. In addition, one program uses the techniques of system analysis to describe the operation of complex systems. Approximately 50 percent of the research funding supports in-house research at Johnson Space Center (JSC) and Ames Research Center (ARC). The rest of the research effort is carried out by seven university-based programs and one independent contractor.

The current JSC program includes:

(1) Supporting the selection of astronaut candidates.

(2) Carrying out collaborative bedrest studies with both NASA investigators from other Centers and with NASA contractors. These include:

 (A) Studies of anti-motion sickness drugs on fluids, electrolytes, and hormones.

 (B) Bedrest studies to document the effect on female and male subjects of various age groups exposed to prolonged bed rest as a simulation of space conditions.

 (C) Studies of drugs (e.g., indomethacin) as potential treatments for postflight orthostatic intolerance. The effects of these drugs on angiotensin and relevant prostaglandins are measured.

(3) Studying mechanisms of fluid and electrolyte balance in non-human primates to insure adequate research models for further space flight.

The projects are technically monitored by the ARC and JSC professional staff. These programs are pursuing ideas that relate to renin/angiotensin/aldosterone response in weightlessness, pharmacologic interventions, renal responses to space flight (real and simulated), development of primate models, and application of system analysis to problem definition and resolution.

The ARC fluids and electrolytes program receives approximately one-half of the funding of the JSC program. This program addresses the effectiveness of bedrest models. A number of studies of male and female subjects are carried out with collaboration of JSC scientists and various NASA contractors. Studies of the metabolic effects of aldosterone and its diurnal variation are underway.

Six university contracts are technically monitored by ARC. These contracts represent work which reflects and matches well with the special competence of the Ames group in the areas of cardiovascular function, endocrine/neural integrative function, and the relation of these to endocrine/renal interactions.

The investigators in this program are generally established scientists aged 40 to 60. Most of the funds actually go to support younger scientists and postdoctoral fellows who are working in the laboratories of the principal investigators.

Critical Questions

The scientific questions fundamental to this area of inquiry are: What is the mechanism for water diuresis and electrolyte changes upon entry into weightlessness in space? What mechanism affects readaptation of fluids and electrolytes to terrestrial conditions upon return to 1 g? Generally, good models exist for pursuing these questions on Earth: Immersion for observations relative to entry into orbit and bed rest for observations relative to weightlessness. Through the use of these models, our knowledge of the mechanism by which the kidney regulates extracellular volume is improving, and an appreciation of the integrated control system composed of numerous interactive elements has been developed. Data from this work would guide future NASA experimentation on Earth and in space. The challenge is to develop carefully planned protocols so that the findings of different groups of investigators will be comparable and potentially useful in developing a new synthesis of data concerning the complex mechanisms that control fluid and electrolyte balance. For example, one must ultimately be able to address questions in terms of which system takes precedence in control of fluid volume and electrolytes when a defined load is placed on an organism.

Other questions are critical to maximally effective programs in this area. For instance, how effective is data from the cardiovascular and bone and muscle research integrated with data from this research program in order to achieve maximally effective synthesis of available information?

Evaluation of Current Effort and Funding

Research within this area is under the leadership of an outstanding group of NASA in-house scientists who have an equally illustrious array of extramural contractors. The questions being pursued are appropriate, and the technologies being utilized to address questions appear to be state-of-the-art. Greater emphasis should be given to the generation of data which can be synthesized into a more adequate picture of integrated functioning of the organism under conditions of weightlessness. Some increased funding is in order to provide increased capacity to hold meetings and encourage exchange of information and to integrate data concerning fluid and electrolyte mechanisms, cardiovascular changes, and mechanisms of bone and muscle alterations.

Projections

The most profitable operating assumption that one might make about changes in fluids and electrolytes under conditions of weightlessness is that these changes are ultimately due to lack of gravity. Thus, the recommendation is that artificial gravity be investigated as a preventive measure for humans spending long periods in space. This gives rise to the following questions: Will artificial gravity prevent changes in fluid and electrolyte balance during long-term space flight? (Data from Kosmos suggests that bone growth was slowed in space in spite of artificial gravity.) Does some similar phenomenon occur in fluid and electrolyte control?

In the long run, questions in this area must consider the quantitative aspects of providing artificial gravity. In order to minimize construction costs in future ships and space stations, the following questions should be addressed:

How nearly does one have to approach 1 g to prevent fluid and electrolyte changes?

How long does a traveler in space have to spend daily in artificial gravity to avoid any undesirable fluid and electrolyte changes?

Can people live in 0 g for long periods and then be gradually reconditioned to 1 g prior to returning to Earth's gravity or leaving their space ship to explore a planet of comparable size? If so, how long a period of reconditioning is necessary?

The answers to these questions will require well-designed experimentation in space or with an available centrifuge.

One must note that the answers to these questions will require an answer to the fundamental question put at the opening of this section. In fact, one very practical question requires similar data: What factors concerning fluid and electrolyte balance and endocrine/renal function should influence the selection of men and women crewmembers or scientific passengers?

What are the consequences of the observed fluid and electrolyte shifts upon the distribution of substances within the various fluid compartments of the body (i.e., total body water, extracellular fluid, circulating fluid, intracellular fluid, etc.)? Closely related to this question are critical questions concerning the effects of the observed fluid shifts upon the pharmaceutical actions, somatic distributions, and dispositions of therapeutic drugs. Another question to be considered in this area of research is the highly practical issue of whether or not the increased calcium, phosphorus, and uric acid excretion is likely to increase the risk of kidney stones and what dietary precautions might be taken to decrease this risk. The propensity of potential space travelers to develop kidney stones should be addressed in selecting candidates for long-duration space flight.

Summary and Recommendations

Weightlessness initiates changes in blood and fluid volumes which are adaptive to space, but may jeopardize the cardiovascular performance of astronauts for hours to days after return to full gravity. Longer periods of exposure cause serious losses of bone and muscle. Observations in space flight and after prolonged bed rest agree in describing these changes, but research is needed to identify the proximate causes and to devise countermeasures to the risks to which the returning astronaut is exposed. Since the measurements of physiological factors involved in the effects of weightlessness are state-of-the-art, careful selection of investigators is needed. Efforts to encourage collaboration and to maximize the yield of information are required.

The NASA Office of Life Sciences is aware of the need for efforts to achieve integration of efforts in related areas of research carried out in different Centers. Greater efforts are needed to achieve these goals. The tendency of Centers to plan joint bedrest studies and to share their unique skills in collaborative work certainly suggests that efforts toward creative integration are not lacking in this program. Nonetheless, one cannot help but be concerned about how well research in this area is integrated with research concerning the problem of increase in central pressure and possible pulmonary hypertension in space. Integrative efforts might be improved by an increase in travel budgets.

Blood

Rationale

A reduction of red cell mass and minor decrease in intravascular erythrocyte packed cell volume with a concurrent reduction in plasma volume has been a consistent observation in both short and long duration flights. In early missions, alterations of plasma immunoprotein concentrations, responsiveness of lymphocytes, and number of leukocytes suggest potential alterations of cellular and humoral mechanisms. In addition, putative radiation effects were to be anticipated as a result of exposure to radiation outside the Earth's atmosphere. Other environmental factors, e.g., oxygen tension and environment-related stress, were postulated to affect the hematopoietic system. Further, the prospect of longer duration space flight may require definition of minimal baseline hematologic parameters for flight and technical personnel.

Status

Red Cell Mass. The typical and significant decrease in red cell mass is considered to be the result of decreased production of erythrocytes, an interpretation based on the observation in Skylab missions that hemolysis is not evident (normal ^{14}C-glycine life span data, ^{51}Cr red cell T½, consistent decrease in reticulocyte counts, normal Fe turnover). The hematocrit and hemoglobin changes are small, and they are difficult to interpret unequivocally in light of the concurrent decrease in plasma. In longer flights, e.g., 84 days, the red cell mass begins to recover after 40 days.

Earlier suggestions that hyperoxic environments contributed to the reduced erythrocyte mass by hemolysis were deduced from the data of the Gemini and Apollo series. The experience of Skylab with normal pO_2 and Skylab studies of erythrocyte metabolism have identified no such defect, specifically, no oxidative damage sufficient to lead to premature cell destruction. The evaluations of erythrocyte membranes have suggested changes of cell shape (increase in echinocytes), altered ion and water permeability (abnormal osmoregulation), but their functional significance is not known.

Lymphocytes and Humoral Immune System. In Skylab missions, no significant changes of plasma protein (total or electrophoretic pattern), immunoglobulins, complement factors, and protease inhibitors were observed. This suggests that earlier alterations were aberrations. Postflight lysozyme levels were found elevated in some individuals. RNA and DNA synthesis by lymphocytes in stimulated culture has been found to be reduced briefly after flight, however, no significant changes were seen in mixed lymphocyte culture, i.e., overall function of T lymphocytes is not changed significantly. Although leukocyte counts increased during the return to Earth, this was transient and not significant. Thus, no functional impairment of the immune and bacterial defense systems has been documented as a result of space flight to date.

Cytogenics. In each of the Skylab missions, minor chromosomal aberrations were found. Structural defects (e.g., chromosomal breaks, deletions, and fragments) were not significantly increased; however, structural rearrangements (e.g., translocations, inversions, and dicentrics) were slightly more common in both flight personnel and their controls than in normal populations. This was thought to be secondary to the use of isotopes in other experimental procedures. The flights themselves (Skylab 2 and 3) do not appear to have contributed significantly to the minor changes, and thus, important cytogenic alterations of blood cells are not anticipated in space flights of these nominal durations.

Ongoing Effort

Current research activities in blood may be classified as follows:

1. Control of erythropoiesis and effects of space flight on erythrocytes

   Activities include studies of erythropoiesis and control of red cell mass, specifically the role of erythropoietin plasma inhibitors and external factors such as weightlessness and hypokinesia on the equilibrium of the erythron. Other efforts include ongoing development of hematologic data bases and monitoring of parameters for individuals involved in space missions, ongoing development (upgrading) of a computer simulation of erythropoiesis and development of automated systems for analysis of biochemical and cellular data in flights. A significant effort involves evaluation of the rat and monkey models for study of erythropoiesis. Other objectives include evaluation of space environmental effects on red cell lipids and on osmoregulation in erythrocytes.

2. Plasma values

   Factors including severe stress, exercise, atmosphere, and rest are under study as potential determinants of plasma volume and for an anticipated relation to erythropoiesis via volume-receptor inputs to erythropoietin production. The role of hypoxia and motion on blood volume is being investigated.

3. Anticipated problems

   Anticipated problems include: evaluation of the interpretation from both Skylab and Salyut missions that a postflight hypercoagulable state develops; study of platelet function; and evaluation of serum enzyme metabolites and lipids.

   The majority of efforts involve scientists and programs at Centers (JSC, ARC); however, projects are current at Scripps, Baylor, Tennessee, and the VA system. Parallel effort, in general, exists in the Soviet space program.

Critical Questions

The priority questions concerning blood relate to the observed reduction of red cell mass and concurrent plasma volume changes typical of space flight. The changes are statistically significant, but it is not evident that in the controlled environment of Skylab-type missions hematologic changes are of any functional significance. In the long-duration Skylab effort, a gradual restoration of cell mass appeared, suggesting that there was adaptation to the initial condition(s) which produced the cell mass and plasma volume changes. Thus the questions are not critical, i.e., limiting to the future programs, particularly short-term efforts such as early Shuttle flights. However, the unique responses of the erythropoietic system in space give a special impetus and opportunity for investigation of the regulation of erythropoiesis. Such studies are, therefore, desirable.

Other putative effects of space flight, e.g., alteration of the immune system, increases in cytogenetic defects, changes in cell composition, have not been found to be significant and thus are not critical.

A. The major efforts concerning erythropoiesis center on regulation of erythropoietin production and "effectiveness" (concentration and inhibition) as a function of space flight (weightlessness), and on major factors which might be anticipated to influence erythropoietic production: plasma volume, stress, exercise, restraint (and rest), and atmospheric alterations. In addition, the rat model is being examined for its suitability to represent erythropoiesis in simulated and real flight. Major limitations on study of erythropoiesis exist in terms of the lack of a pure erythropoietin and feasible radioimmunoassay; however, the current work is appropriate and necessary. The computer simulation represents a convenient data handling system to correlate and evaluate data concerning the many parameters according to the popular model of erythropoiesis. It appears to have limited potential for simulation in that the current understanding of erythropoiesis has limitations.

Evaluation of potential hemolysis as a contributor to reduced red cell mass involves CO isotope methods in a monkey model and, in light of reported cell life span reduction from Kosmos 783 flight data, may have justification. (Note that the Skylab data do not support the conclusion that hemolysis contributes beyond the early phase of flight.)

Studies of the putative hypercoagulable state rely on X-irradiation to remove mucopolysaccharide from endothelial surface; correlation of this change is made with *in vivo* coagulation time.

Effects of zero gravity on erythrocyte osmoregulation are being evaluated by standard methods for measurement of ion permeation, water content, and osmotic fragility. Studies of changes of lipids in erythrocyte membrane and of shape changes utilize standard methods for lipid analysis and electron microscopy. A very interesting and potentially fruitful project on the effect of weightlessness on normal mammalian cell proliferation using the erythroid cell as an example of modification and repair, examines the effects of variables on pO_2, pN_2, and pressure in a simulator (rat and rabbit models) on kinetics; a second phase involves proposed studies on an early Shuttle flight, in collaboration with the JSC effort.

B. The efforts in this research are, in general, those of senior scientists and clinicians and there is very little evidence that younger individuals are contributing to or being attracted to the field. The balance between university/private sector and NASA appears appropriate.

Adequacy of Current Program Effort

Overall, the effort is heterogeneous in terms of quality, importance of goals, and critical approach to objectives. The work is at a plateau of evolution from the efforts stimulated by the initial observations in early manned flights.

Changes in red cell mass: This question has been significantly illuminated by the later Skylab efforts, and it would appear that the decreased mass relates to changes in vascular volume and decrease in marrow stimulation. An initial hemolytic phase at the outset of flight cannot be ruled out completely and the argument of early splenic congestion with augmented destruction is logical, albeit not supported by data/observation. The studies of suppression of erythropoietin and/or androgens are promising and desirable, but may be extremely difficult at the present state of knowledge of erythropoietin biochemistry/physiology. The use of a primate model is attractive if zero gravity could be maintained long enough to allow good life span ($T_{1/2}$ and glycine) studies, and careful evaluation of marrow function throughout a weightlessness period. (Since Shuttle experiments will be short duration, the chance to evaluate marrow/circulatory erythrocyte mass balance will be limited.) The rat model may have some value, but it is unlikely that conclusive data can be obtained from Cr life span of rat cells during a flight: life span studies simply aren't precise enough to make it worth the time and instrumentation costs. Since the red cell mass change is not of functional significance, major efforts may be appropriately deferred to later flights and until better erythropoietin biochemistry and quantification are available.

Plasma volume alteration: The efforts to understand blood compartment volume shifts are appropriate and being addressed well. Since this altered physiology has great significance for cardiovascular conditioning, greater emphasis on vascular volume regulation would be appropriate. Additional work by prominent investigators would be desirable.

Alteration of red cell surface structure: There is no evidence to date that echinocytic cells are rheologically abnormal; and further, there is no strong evidence that these cells affect the endothelium of the vasculature. At this time, studies of osmotic fragility and ion permeability are not based on a carefully-established hypothesis, and represent data collecting endeavors which *a priori* cannot be expected to yield new insights. Studies of specific gravity profiles likewise cannot, of themselves, be interpreted exclusively. In the past, this area of research has appeared to be of questionable value, and perhaps should be redirected.

Health assessment criteria: In light of the experience to date, one may conclude that, from the hematologic standpoint, any normal individual could be expected to tolerate flights up to three months with no adverse hematologically significant effects. Data should be collected on individuals who have experienced space flight to identify possible late-appearing changes.

Studies of weightlessness on hematopoietic tissue proliferation: These studies are of broad general interest and may be prototypical of efforts in other cell types.

Influence of external parameters on blood volume: Efforts to define influence of stress, composition of atmosphere, and exercise/rest on blood volume (and hematopoiesis) are desirable. The issue of oxygen toxicity appears adequately resolved, at least to the extent that a large effort is not warranted. No medically significant evidence of oxidative effects on red cells has been identified, and thus does not appear to be a fruitful direction. Life span studies of erythrocytes are not promising. Studies of effects of lipids in structure and function of erythrocytes have not led to significant new concepts. In light of the normal life span of human cells in the Skylab experiments, these efforts have been redirected.

Computer simulation of erythropoiesis: This existing facility is useful for correlation of data. This approach in isolation is not likely to produce any novel findings. Its usefulness will depend upon the soundness of data and concepts utilized in constructing simulations. The quality of hematologic intelligence which guides the achievement of this simulation is critical to their usefulness.

Effects of space flight on vascular permeability and flow: In light of the observed normal erythrocyte life span, the justification of the cellular (blood cell) portion of the work is weak. If vascular permeability alteration is presumed to correlate with vascular volume change, there is little evidence to support the concept. The existence and significance of hypercoagulability should be established prior to correlative experiments.

Funding. Funding, overall, is adequate, and redistribution of this effort into more promising areas is in progress. Evaluation of the success of this redirected effort will deserve future review.

Priorities. The two priority efforts should be on 1) regulation of marrow function (erythropoietin and vascular volume effects) during space flight, and 2) effects of external factors, stress, weightlessness on cell proliferation. Other efforts should receive less emphasis or be phased out in favor of greater concentration on these two areas.

Summary and Recommendations

Studies of blood, its elements, production, the volume of vascular compartments, the cellular and immune systems, and the long-term postflight hematologic parameters indicate that red cell mass declines (probably due to suppression of erythropoiesis) and other elements and the immune systems are not affected by space flight up to three months. The erythroid mass appears to commence recovery after approximately 40 to 60 days. Long-term follow up does not suggest late hematologic effects, and information to date indicates that no particular new specification concerning hematologic parameters is required in selection of personnel.

Recommendations. The investigations concerning regulation of erythropoiesis should continue, and the contribution of hypovolumia via erythropoietin deserves to be continued. Characterization of experimental animals is worthy; however, the development of elaborate instrumentation to evaluate parameters of questionable value (e.g., ^{51}Cr life span studies) is dubious for short-term flights. Studies of stress, exercise, and weightlessness on mammalian cells, including hematopoietic cells, should continue.

Radiation

Rationale

Any space travel above very low Earth orbits necessitates exposure of personnel to potentially high radiation dose rates in the geomagnetically trapped radiation belts or, outside of the Earth's magnetic field, to the high energy heavy particle radiation (HZE) flux (cosmic rays). Activities in space currently under consideration will necessitate exposure of space vehicles and crews to more intense regions of the geomagnetically trapped radiation belts or to large accumulated fluences of HZE particles. The current consideration of large-scale operations at a geosynchronous altitude generates a need for the development of certain knowledge and technology. This need becomes pressing considering the requirement for accurate planning to determine the future course of space flight. The space radiation environment (trapped radiation and HZE particle flux) will be a major design consideration for these activities. It is of obvious and major importance to know if additional shielding must be introduced to protect personnel from exposure to these radiations.

Radiations in the geomagnetically trapped radiation belts are principally those that have been studied extensively in the laboratory, i.e., protons, electrons, gamma rays, and neutrons. While some problems remain in the valuation of the effects of these radiations, NASA need not contribute heavily to the large amount of investigative work currently being done on the effects of these radiations. The basic effort of the radiation effects research program must be the determination of the biological effects of those components or factors of the space radiation environment that are unique and for which no prior ground-based experience is applicable. There must be emphasis, therefore, on investigating the response to high energy, heavy, multi-charged (HZE) particles, including the basic mechanisms of damage to living tissues. This area presents, potentially, the greatest hazard to long-duration manned space flight, and the level of hazard must be adequately characterized before extended activity at geosynchronous locations can take place.

The problem has been summarized well in the National Academy of Sciences report, *HZE Particle Effects in Manned Space Flight*.

> *We conclude that the HZE-particle question need not be considered a barrier to planning long-duration manned missions, but we recommend that a quantitative assessment of the potential hazard of these particles to man in space should be in hand before any such missions are carried out beyond the Earth's magnetosphere or high-inclination Earth orbit.*

The report goes on to estimate that it will require five to ten years to obtain the necessary information, making it imperative that research continue without delay.

In addition to natural sources of radiation, onboard nuclear sources and radioisotopes may result in some additional exposure. In a solar power station, astronauts may also be exposed to high levels of microwave radiation. Adequate information on the effects of these man-made sources is available or being generated by research supported by other agencies.

Status of the Problem

HZE particles are so named because they are stripped nuclei of relatively high atomic number, accelerated to energies sufficiently high to permit penetration into tissue to depths of from several millimeters to many centimeters. Although the range of Z for HZE particles is arbitrary, those of most biological significance are around the value of 26, the atomic number of iron (particles of higher Z are quite rare). The trajectories of these particles tend to be straight. As they pass through matter, they undergo collisions with electrons that were initially bound to the molecules of the medium. The molecules are thereby ionized or left in an excited state. The struck electron often picks up enough momentum in the collision to travel a considerable distance in the material, ionizing and exciting molecules along its path. In fact, most of the "damaged" molecules of the medium are caused by these secondary electrons (delta rays) rather than by collision with the primary HZE particle. For high values of Z, the energy deposited in tissue along the particles' trajectory can be enormous. The energetic charged particles undergo nuclear interactions in tissue and the shielding material, often resulting in fragmentation, spallation, and star production, all of which causes the deposition of a large amount of energy in nearby cells. It is the unusual patterns of energy deposition in tissue cells along the HZE particles' trajectory that leads to the potentially unique biological effects of these particles.

The tracks of HZE particles in tissue can be divided into three regions. In the *peripheral* region, the radiation field is that of the secondary electrons. It resembles an X– or gamma ray field. The outer dimensions of the peripheral region are determined by the kinematic limit on the momentum that can be transferred to an electron in a collision and the range of that electron in tissue. At low energies the kinematic limit on momentum is reduced, resulting in the *"thindown"* of the track despite the sharp rise in the energy deposition in this region. The energy density in the case of a thindown track (i.e., near the end of its range) greatly exceeds all levels known for conventional kinds of densely ionizing particles. The *core* of *medium and high energy particles* has a large energy density that falls off rapidly with distance from the primary trajectory.

In order to make explicit the unique potential effects of HZE particles, it is useful to review briefly the cardinal effects of more conventional radiations in cell systems and in body organs. These effects can then be compared to and contrasted with the potential effects of HZE particles.

The organs of the mammal are made up of cell systems, and the organs can be categorized roughly on the basis of whether or not the cells of that organ normally and routinely divide in the adult individual. In many organs, e.g., the skin, bone marrow-blood lymphopoietic, bowel (epithelium), and male gonads, the organ system is composed partly of "progenitor," or "factory" cells that divide frequently, and partly of mature "functional" cells that actually carry out the principal function of the organ and then die. These organs are known as "turnover" or "renewal" systems. In contrast, in many organs, e.g., liver, central nervous system, and muscle, the principal cells that carry out the main function(s) of the organ rarely, if ever, divide, and the functional cells in the very old individual are the same as those that were present when the individual was very young.

It is essentially axiomatic in radiobiology that dividing cells are sensitive to radiation in terms of serious injury to or death of the cell, and that non-dividing cells are extremely resistant to injury and death. Serious injury or death in dividing cells appears to be related to damage to the DNA, and injury does not become visible or manifest until the cells actually divide.

In tissue culture studies, death of these dividing cells is typically due to the loss of the cell's ability to divide, and sublethal injury is often studied in the form of some mutation or chromosomal damage that is easily distinguished in the irradiated cell or in the next generation of cells. None of these is applicable to non-dividing cells. Cell death for a non-dividing cell is usually scored in terms of destruction of the cell, and injury studied is often measured in terms of the threshold potential required for stimulation. There is good evidence that potentially lethal damage in non-dividing cells of an organ can remain dormant for a substantial fraction of the organism's life span, but that such damage can become manifest if the cells can be stimulated to divide.

Early (hours to weeks) radiation effects following exposure to moderate doses of radiation (tens to a few hundred rads) in the mammal are the result of injury to and death of dividing cells, leading to *organ* dysfunction and failure when a substantial fraction for the total cells in that organ are severely injured or killed. Organ dysfunction, in turn, leads to symptoms and signs, and to death of the organ if the dose is high enough to cause such injury to a vital organ. These effects are limited at moderate doses to renewal systems, i.e., marrow-blood, lymphopoietic, GI eptihelium. Death results if a vital organ, such as the bone marrow-blood or GI epithelium, is so compromised.

Damage to non-renewal systems, such as the brain and liver, can occur at these moderate doses, but it probably is not due to direct injury to the cells of those organs. If such damage occurs, it most likely is secondary to functional changes in supporting renewal systems or structures (supportive tissues and blood vessels), the function of which has been impaired by the radiation exposure. Direct damage to non-dividing cells occurs only if the radiation dose is very large, many times higher than the lethal dose associated with damage to renewal systems.

Late effects, such as carcinogenesis, obviously must be related to cells that are altered or injured, but which can live and propagate indefinitely. Such changes can be induced in dividing (or in normally non-dividing) cell systems, and tumors can be induced in a number of organs at doses that are considerably below the lethal level for the organism. Effects in large populations can be seen at dose levels so low that early changes of any kind can be detected only by means of very special techniques, if at all.

Damage to dividing cells can be studied easily in tissue culture, and tissue culture systems represent an excellent model for study of the "stem cells" in cell renewal systems in the intact mammal. Dose-effect curves for populations of dividing cells in tissue culture are shown in Figure A-1. Note curve A, which is obtained with "high-LET" radiation, such as alpha particles or the recoil protons from irradiation of tissue with fast neutrons, in the energy range of several tens to a few hundred keV. Note that the curve is exponential, i.e., the kinetics are "single hit," and each cell inactivation results from the passage of a single charged particle through the cell. This exponential curve is to be contrasted with curve B, obtained with exposure to "low-LET" radiations such as X-rays, gamma rays, or electrons. There is a clear-cut "shoulder" on the curve, indicating "multi-hit" kinetics, i.e., sublethal damage must accumulate in the low dose region before appreciable cell inactivation can occur. The curve then becomes exponential, i.e., essentially all cells have sustained "n-1" hits, and now only one more hit is required for exponential inactivation thereafter.

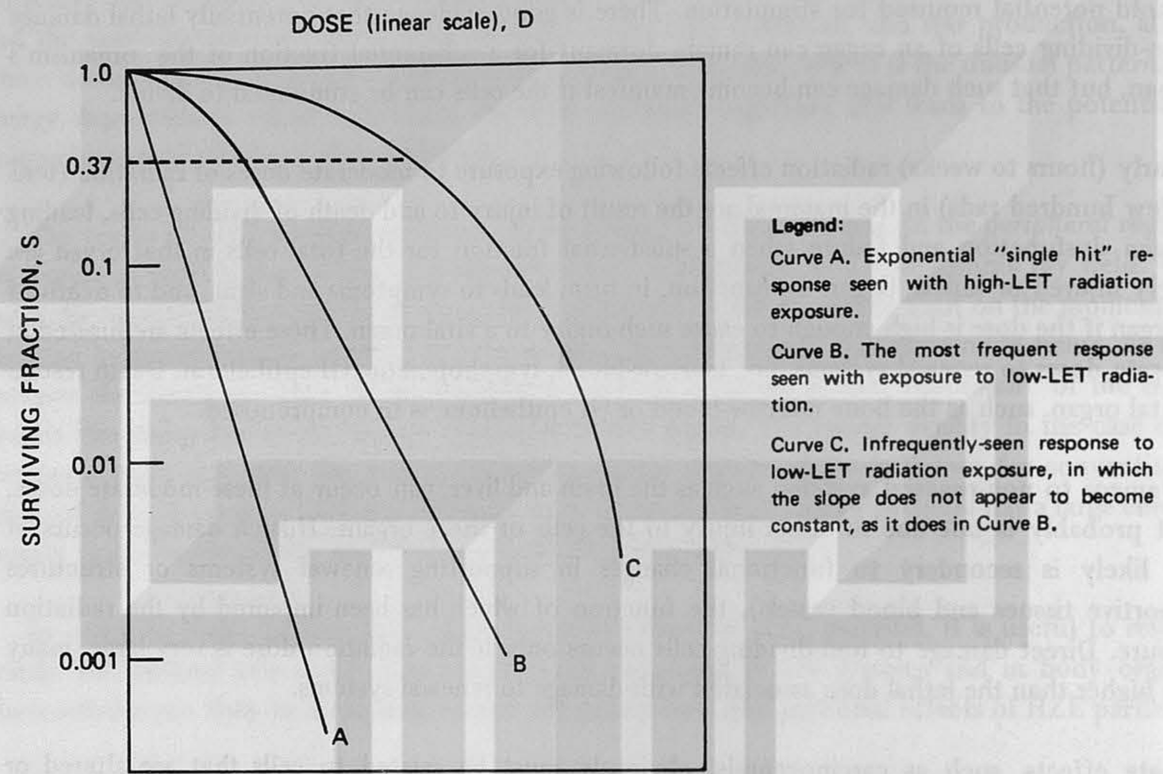

Figure A-1. Types of cell survival curves encountered in radiobiology.

With "single-hit" kinetics, the degree of effect per rad is independent of dose magnitude, and independent of the time pattern of dose delivery, i.e., there is no effect of dose rate on the effect per rad. The situation is in marked contrast to that seen with "multi-hit" curves. Obviously, the effect per rad is a function of dose, i.e., the slope of the curve becomes steeper as the dose decreases. Also, recovery is possible from sublethal damage. Thus, if the total dose is protracted in time, there can be near-complete recovery from sublethal lesions such that a greater total dose must be applied to produce the same degree of biological effect.

With single-hit kinetics, only the passage of a single particle through the cell nucleus is required for cell inactivation or death. The converse, however, is not true. Not every particle that traverses the nucleus results in cell inactivation or death. Hence, some cells can be injured, and this injury can become manifest as chromosome damage, giant cell formation, etc. Some injured cells can propagate indefinitely, and some cell injury can lead to transformation of cells and malignancy. Such transformed cells give rise to a malignancy if the transformed cells are injected into a suitable recipient host. The kinetics observed for cell transformation are similar to those observed for cell killing, i.e., the curves shown in Figure A-2 for cell inactivation are very similar to those obtained for cell transformation. Obviously then, high-LET radiations can produce injured or transformed cells that can propagate and give rise to malignancy.

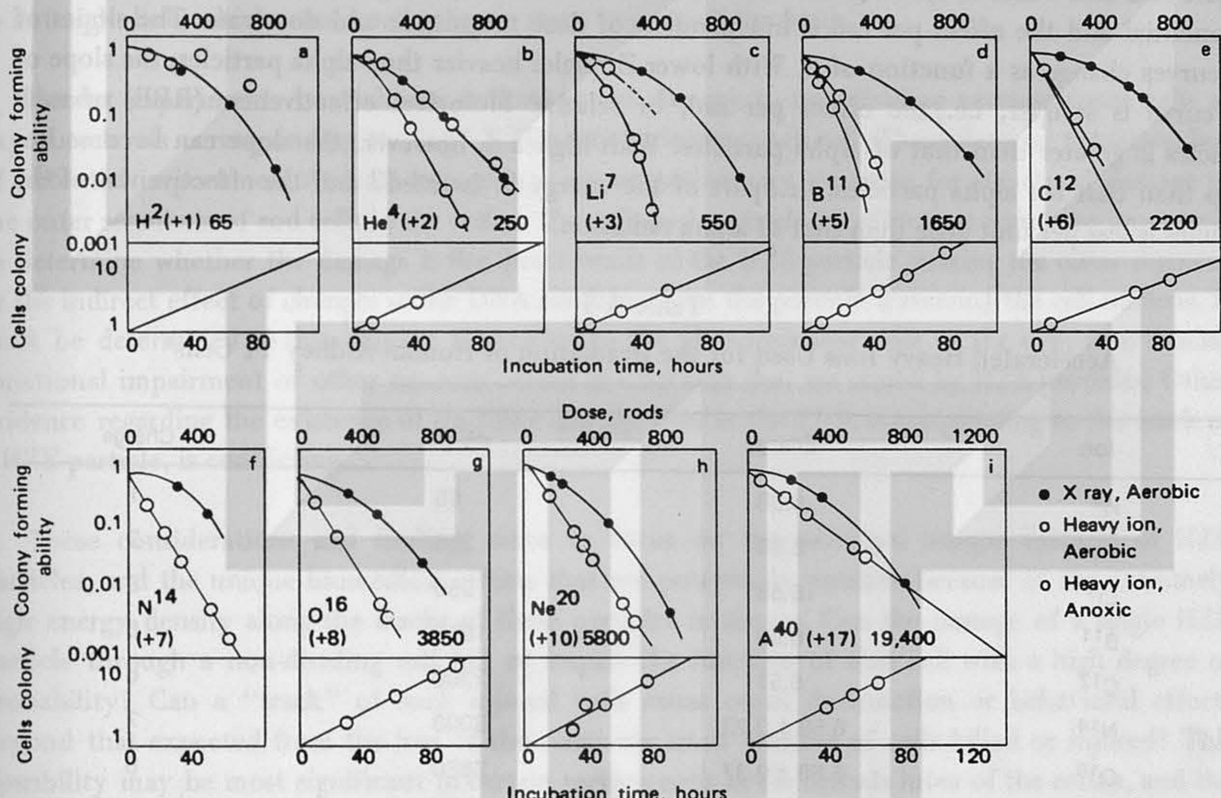

Figure A-2. Response of T1 cells to irradiation with heavy ions of equal velocity. The curves, left to right, top to bottom, are for the ions (descending order). The abscissa legend, top, is the does in rad. The solid circles are for X-ray controls. (From Todd, and similar to that shown in *Radiation Research, Space Radiation Biology*, Supplement #7, September 7, 1967, p. 196).

Non-dividing cells, however, cannot be studied in tissue culture as can dividing cells. Non-dividing cells can be maintained for relatively short periods of time in culture, but the time available for observation is restricted. From limited studies in maintenance tissue culture, however, and from extensive histologic studies in tissues, it is clear that the passage of a single alpha particle is incapable of destroying non-dividing cells. Similarly, the passage of a single alpha particle through the cytoplasm of a dividing or non-dividing cell (cell nucleus not hit) is incapable of seriously injuring or killing the cell.

With the above discussion of the principal effects of radiations commonly available in the laboratory, one is in a position to examine and contrast the effects of HZE particles. The effects of accelerator-produced beams of HZE particles have been studied extensively in dividing cell systems grown in tissue culture, and in most respects they act in a fashion similar to alpha particles (Figure A-2 and Table A-1). Single-hit kinetics are observed frequently, i.e., the dose effect curve is exponential and the effect per rad is independent of dose magnitude and dose rate. The slopes of the curves change as a function of Z. With lower-Z nuclei heavier than alpha particles, the slope of the curve is steeper, i.e., the effect per rad, or relative biological effectiveness (RBE) of such particles is greater than that of alpha particles. With higher Z, however, the slope can become less steep than that for alpha particles, i.e., part of the energy is "wasted" and the effectiveness of the particles is less per unit dose than that of alpha radiation.

Table A-1

Accelerated Heavy Ions Used for the Irradiation of Human Kidney T1 Cells[a]

Ion	Energy	dE/dx	Charge
H^2	6.58	65	1
He^4	6.58	250	2
Li^7	6.58	550	3
B^{11}	6.58	1650	5
C^{12}	6.57	2200	6
N^{14}	6.50 ± 0.23	3000	7
O^{16}	6.58 ± 0.37	3850	8
Ne^{20}	6.58	5800	10
Ar^{40}	5.70	19400	17

[a]Energies are expressed in MeV per nucleon, and stopping powers (dE/dx) are expressed in MeV-cm^2/g in tissue. Charge is given in units of positive electron charge.

Legend: Physical characteristics of the ions used to obtain the dose-effect curves are shown in Figure A-2.

There are important differences, however, between the effects of HZE particles and alpha rays. As Z increases, the cross section for inactivation of dividing cells becomes greater than the geometrical cross-section of the cell nucleus. One probable interpretation of the phenomenon is that it may not be necessary for the particle to traverse the cell nucleus in order to inactivate the cell. The implication of this is substantial, i.e., HZE particles, in contrast to other radiations, may be capable of inactivating cells through a mechanism that does not involve direct traversal of or damage to the cell nucleus. This would lead to the expectation that these particles might be capable of inactivating or seriously damaging non-dividing cells, by passage of a single particle. *In vivo*, these damaged cells would be expected to lie along the straight trajectories of the HZE particle. If, however, the nucleus of non-dividing cells must be hit for death or injury to result, then a straight "lesion" of dead or damaged cells would only occur when the much smaller cell nuclei actually lie in a straight line, which would not occur in many regions of the brain.

Recent experiments have shown indications of damage to non-dividing nervous tissue cells at exposure levels corresponding to single HZE particles hitting each cell. These data are tentative, but of potential importance. At least two groups report preliminary evidence for structural damage to the outer segments of rod cells in the retina. If confirmed as single-hit effects, it would be important to determine whether the damage is the direct result of the HZE particle striking the outer segment or the indirect effect of changes in the DNA resulting from the particle traversing the cell nucleus. It must be determined if this damage is peculiar to the photoreceptor cells of the eye, or if similar functional impairment of other neurons occurs in CNS cells that are struck by HZE particles. Other evidence regarding the existence of tracklike damage sites in the CNS, corresponding to the track of a HZE particle, is conflicting.

These considerations and findings serve to focus on the principal unique features of HZE particles, and the unique biomedical effects that are potentially possible because of the extremely high energy density along the tracks of these particles in tissues. Can the passage of a single HZE particle through a non-dividing cell kill or impair the function of that cell with a high degree of probability? Can a "track" of such injured cells cause organ dysfunction or behavioral effects beyond that expected from the loss of the relatively small number of cells killed or injured? This possibility may be most significant in certain regions such as the macula lutea of the retina, and the amygdyla or hippocampus of the brain. Equally important, what is the potential of such particles to induce malignant transformations in such cells or tissues: If such effects are in fact possible, they would be expected to be completely independent of dose rate, i.e., repair of such damage would not be possible, nor can the non-dividing tissues regenerate cells that are killed in this manner. Thus, even extremely low fluences might lead, over a period of time, to the functional inactivation or death of a substantial fraction of cells in an organ and possible serious organ functional impairment.

Obviously, exposure to HZE particles would never, in space missions, lead to early acute effects of radiation due to death of dividing cells and consequent failure of organ function. The doses and dose rates are far too low, and the dividing cell systems can replace cells as they may be destroyed. HZE particles will constitute a serious problem in space only if they can damage non-dividing cells with a probability high enough either to lead to sufficient cell depletion to result in impaired function in a non-renewal organ, or to tracklike arrays of damaged cells that, in specific regions of the retina or CNS, may result in significant changes in function or behavior. Neuronal damage that leads to functional impairment or behavioral damage may or may not also result in morphologically observable damage. This emphasizes the importance of neurophysiological and behavioral testing. Such testing can be carried out with animal subjects in laboratory experiments simulating worst-case conditions by exposure to iron or argon nuclei at levels somewhat larger than, but comparable to, the total HZE exposures to be expected in space. Because of its importance, behavioral testing should be performed by well-qualified individuals using protocols in which the primary objective is to study behavior.

The above discussion of the possible unique biological effects of HZE particles indicates also the reason that conventional dosimetry is not satisfactory for the characterization of exposure to these particles. With conventional radiations, the production of lesions within the nuclei of cells is a stochastic process. The degree of effect is related to the average energy density, expressed as ergs per gram, and to the "radiation quality," the fine structure of energy disposition frequently characterized as the energy density of individual radiation "events" leading to lesions or sublesions. In the case of damage from HZE particles, however, interaction is ordered, and occurs in cells along the trajectory of the particle in tissue. Thus, the probability of effect is related more to the fluence of particles expressed in events per square centimeter, and the cross-section for cell damage or inactivation, rather than to the total energy absorbed per unit mass of tissue. Thus, it becomes evident that new conceptual approaches to characterizing exposure to HZE particles are necessary, and that newer approaches to dosimetry will be required to characterize the exposure adequately.

Ongoing Efforts

All known directly-relevant efforts to solve the key dosimetric and radiobiological problems related to effects of HZE particles are being supported by NASA. The Radiation Effects and Protection portion of the NASA Life Sciences Program resides within the Medical Sciences Division and is carried out in-house at ARC and JSC and by grants and contracts with various universities. There is also one DoD effort at the USAF School of Aviation Medicine at Brooks. The program is almost entirely concentrated on studies of HZE radiation and has as its central effort the support of several studies at the Bevalac facility of the University of California at Berkeley. Five program tasks are directed toward long term, low dose effects in mice, rabbits and cell cultures; two are investigating tracks in nervous tissue produced by higher dosages; three are devoted to improved dosimetry techniques, and one to improved dose expression. One limited duration study is investigating the light flash phenomenon produced by HZE; one task is seeking to further develop retinal photographic techniques to identify minimal changes in the living eye; and one recently initiated effort is developing three dimensional HZE transport equations for use in devising improved shielding techniques. Finally, a long term study at Brooks utilizes a unique colony of monkeys which had been exposed to varied doses of proton and electron radiation between 1964 and 1969 to investigate long term (delayed) effects.

Critical Questions

The key radiobiological and dosimetric questions have been discussed above, and are given below:

(1) Can the passage of a single HZE particle through non-dividing cells, such as those of the central nervous system, lead to a high probability of resultant functional impairment or death of the cell? The corollary question is, can the resultant cell death lead, in the course of sustained activity in outer space, to functional impairments of units of the central nervous system?

(2) Will the killing of non-dividing cells in critical organs such as the brain result in impaired performance to a degree that might compromise an astronaut's ability to complete a space mission satisfactorily?

(3) What is the probability of exposure to HZE particles in space giving rise to delayed effects either in the form of behavioral changes, impairment in organ function, or malignancy?

(4) Is it feasible to shield against HZE particles, with acceptable cost in added weight?

Most of the above questions are being studied, using a variety of biological materials exposed to HZE particles produced by the Bevalac machine in Berkeley. The irradiated material is being studied at the Donner Laboratory in Berkeley, the Ames Research Center, the Johnson Space Center, the University of San Francisco, the USAF School of Aerospace Medicine, Colorado State University, the University of West Florida, and Clarkson College of Technology. Excellent investigators are working on the problems, and there is an appropriate mix of older, experienced workers and young, enthusiastic individuals.

Adequacy of Current NASA Program

The overall program is adequate. Increased attention should be paid, however, to the development of better means of determining if the passage of a single HZE particle through the nucleus and/or cytoplasm of non-dividing cells can impair the function of or severely injure the cell. Because of the difficulties entailed in doing this, added attention should also be given to studying behavioral changes in the intact organism irradiated with HZE particles at fluences unlikely to lead to interactive effects among individual cells (or linear arrays of cells) potentially injured by the passage of a single HZE particle. Studies in shielding methods, including the testing of models, should be pursued.

Funding. Funding is adequate for current studies, but is not sufficient to insure that needed additional studies on mechanisms of cellular damage by HZE particles or behavioral studies will be pursued with the necessary vigor.

Priorities. Current priorities have been adequately assessed. Additional studies suggested above should not be done at the expense of current studies.

Future Projections

It is reiterated that although the hazard of exposure to HZE particles may be minimal, the total impact on extended manned space flight could be serious, and even prohibitive, should the reverse prove to be true. Hence, it is mandatory that studies on possible effects of HZE particles be pursued vigorously now, to provide necessary input to planning for the future course of space flight.

Summary and Recommendations

The NASA radiobiological resources should be dedicated to the following high-priority objectives in research of HZE particles for the purpose of gaining information needed in risk estimation, and for decisions concerning acceptable levels of exposure:

(1) Every effort should be made to develop and use maintenance cultures of non-dividing cells to study directly the effects of HZE particles on these cells.

(2) Quantitative dose-response relationships are needed for delayed pathologic and behavioral effects, and effects on life span, resulting from whole-body exposure of small laboratory rodents to HZE particles (e.g., three Z numbers covering the available range). It is stressed that "doses" and/or "dose rates" must be low enough to minimize tissue damage or interaction between cells "hit" by a particle, i.e., total exposure should be comparable to that expected in space missions. Large "doses" of HZE particles result in complex tissue damage which bears no relation to the problem encountered in space.

(3) Quantitative dose-response relationships are needed for delayed neuropathologic effects (neuronal cell impairment, killing, and loss) in correlation with neurophysiological and behavioral parameters, visual acuity, and effects on life span, resulting from whole body (or head only) exposure of animals to HZE particles.

(4) Flight exposure profiles and mathematical modeling for dose-response relationships are required.

(5) Improvement of physical dosimetry techniques and automation, radiobiologically meaningful dose expression, and dose-distribution modeling is needed.

(6) Long-term followup is required of eyes of human beings exposed to radiation in space, with development of a protocol and a grading system for recording aberrations in the lens and retina.

(7) Approaches to shielding need to be developed and tested.

(8) Visual phenomena seen by astronauts ("light flashes") have been produced repeatedly in the laboratory by exposure of human beings to high energy ionizing particles. While additional investigative work could not be given high priority, on the basis that the phenomena are associated with significant hazard, it is important that additional research be done to clarify the uncertainties surrounding the biophysical mechanisms involved.

Space Motion Sickness

Rationale

Perhaps 20 to 50 percent of those exposed to weightlessness, with a relatively spacious surrounding environment (e.g., Apollo Module, Skylab, or Space Shuttle), will develop "space motion sickness." This condition has the potential for limiting the effectiveness of individual performance for up to three to five days. In Skylab, with highly motivated crewmembers who had been exposed to extensive "over-training," crew performance time lost did not exceed one day (*Biomedical Results from Skylab*). In Space Shuttle, it is anticipated that the science specialist will not have been over-trained. He must be able to modify onboard experiments to take advantage of novel opportunities in scientifically creative ways. It is reasonable to predict that high order creative thinking and behavior are required to carry out this responsibility successfully. Such performance requirements are likely to be more susceptible to the disabling effects of space motion sickness. Since duration of symptoms of such sickness is generally time limited, this problem is of maximal importance to short duration space flight (e.g., Space Shuttle). Biomedical research concerning this problem is directed toward its prevention and treatment.

Additional rationale for studying the mechanisms of space motion sickness and vestibular function in flight is to estimate the role of gravity in sensory motor adaptation. The vestibular apparatus in the inner ear is a very ancient organ in animals for sensing the gravity vector (g). Thus, scientific studies of the vestibular apparatus, and its central nervous system connections under varying g, are relevant to "gravitational biology." In their broadest context, these studies increase our understanding of how gravity has shaped the evolution of the sensory integrative apparatus of animals.

Status

Space motion sickness is a self-limited illness which occurs as a consequence of the interaction of factors which characterize space flight under conditions of null gravity. The signs and symptoms of space motion sickness are identical in form to those of terrestrial motion sickness. These include such primary symptoms as postural illusions, sensation of rotation nystagmus, and what is often termed dizziness or vertigo. Following the onset of these symptoms, an individual frequently develops second order symptoms of skin pallor, yawning, increased salivation, increased perspiration, headache, malaise, nausea, and vomiting. Not surprisingly, individuals with these symptoms have a poor appetite and may display a loss in performance efficiency. Occasionally, such manifestations of terrestrial motion sickness may be sufficiently severe and prolonged to lead to loss of enough fluids and electrolytes to produce severe dehydration. This has not been a consequence of space motion sickness to date.

The NASA research program on space motion sickness has focused on developing scientific knowledge that will permit a more thorough understanding of the causes of space motion sickness in 0 g and to apply this knowledge by:

(a) Identifying non-susceptible individuals prior to flight,

(b) Developing satisfactory methods (e.g., pharmaceutical or training) for the prevention of the problem,

(c) Developing methods (e.g., pharmaceutical) for the treatment of symptoms when they occur.

In order to accomplish these goals, a program of interrelated studies has been undertaken to delineate the causes of space motion sickness and to utilize that information in the development of effective means for prediction, prevention, and treatment. The symptoms of motion sickness are usually elicited when a rapid transition is made from one motion environment to another. In order to analyze the perceptually complex phenomena of motion in space, humans must sample multiple aspects of the environment simultaneously and centrally integrate the multi-channel input of data. In man, three primary sensory systems provide major inputs to this process:

(1) the visual system

(2) vestibular function

(3) muscle/joint proprioception and other peripheral sensory modalities.

Under normal circumstances, these systems are highly tuned to gravitational/spatial inputs. The following discussion will focus on the vestibular organ, because of its importance to the problems of both terrestrial and space motion sickness and because it contains one of the best understood gravity sensors.

The vestibular organ consists of three semicircular canals which freely communicate with an open space called the utriculus. These canals are critical to the perception of rotary motion and may or may not be involved in the perception of gravity. Although the semicircular canals play an important role in the induction of certain kinds of terrestrial motion sickness, there is some evidence to suggest that they may not be responsible for the disturbances that have as their consequence space motion sickness (i.e., experiments in space seem to suggest a decreased sensitivity to rotary motion, at least after several days of adaptation in the weightless environment).

In addition to the semicircular canals and their associated sensors, the vestibular apparatus contains three otolith organs.

The following comes from O.G. Lowenstein in the *Handbook of Sensory Psychology VI/I, Vestibular System Part II Basic Mechanisms,* and may help the reader appreciate the otolithic organs in space motion sickness.

> *The otolith organs are differential-density gravity sensors. A relatively specific heavy mass of calcareous material lies anchored to and partially imbedded in a jelly-like otolith "membrane" which in turn overlies a sensory epithelium, the so-called "macula statoconea" . . . The hair processes of the sensory cells project into the otolith membrane and are mechanically deformed by the displacement of the otolithic mass relative to the sensory epithelium. Such displacement occurs when the otolith organ changes its spatial disposition relative to the vertical as the head is tilted.*

Not surprisingly, organs constructed explicitly to sense gravity may produce an aberrant input into the central nervous system when this organ is called upon to operate in a weightless (zero gravity) environment. Preliminary observation on frog otolith indicates that under conditions of weightlessness the otolith organ responds by over- and under-activity, changing on a time-base of tens of hours. It appears that these changes are the complex consequences of stimulus conditions created by weightlessness and response of the CNS mediated through efferent inputs into the vestibular system in general, and the otolith organ in particular. Perhaps these connections are the way the brain acts to control the input function of the vestibular apparatus. The role of the otolithic portion of the vestibular system appears central to dysfunction of this system in weightlessness since it is explicitly sensitive to linear and constant gravitational stimuli. It is thought that although this otolithic dysfunction is a necessary step in the sequence of events that lead to motion sickness, it serves as a necessary, rather than sufficient, condition for the development of space motion sickness.

The explanation of space motion sickness having the most current support among workers in the field visualizes the production of motion sickness as being a consequence of sensory conflict. This explanation presumes that visual, proprioceptive, and vestibular inputs have been so integrated that when the organism is transferred into a novel motion environment, the inputs from one or more parts of the system disturb the established adaptive balance between the systems. Given a few days, a new adaptive balance is established between these various input systems to afford new adaptive integration to the organism. Prior to the establishment of this new adaptive organization, it is assumed that over-activity in connected portions of the system results in the activation of the autonomic (visceral) nervous system with the result that symptoms are produced in susceptible individuals. If this theory of sensory conflict is the appropriate one, then one might predict that the symptoms of space motion sickness are the result of the effect of zero gravity stimulation upon the otolith organ. That is, the zero gravity vector produces sensory input into the central nervous system which the central nervous system interprets as being in conflict with its inputs through its other afferent channels (e.g. the visual system). The subject might usually sense that he is moving rapidly through space, but the otolith, perceiving zero gravity, is telling the brain that the person is stationary. This model of "sensory" conflict would seem to predict that an individual whose sensory/CNS apparatus is adapted to the 0 g environment would develop motion illusions upon return to the 1 g environment. This has been identified as being a correct prediction. The same conceptual model of "sensory" conflict to explain terrestrial motion sickness can be used to explain space motion sickness. Although a disturbance of the same basic functional relationships with the nervous system may be involved to explain both terrestrial and space motion sickness, it is of importance to note:

(a) that space motion sickness occurs in individuals who are relatively resistant to motion sickness and that tests for susceptibility to terrestrial motion sickness do not predict susceptibility to space motion sickness,

(b) that activities such as aerobatics, which tend to increase resistance to the development of certain kinds of terrestrial motion sickness, did not prevent space motion sickness in Skylab crews,

(c) that the pharmaceutical treatments that are effective in suppressing terrestrial motion sickness may be less effective in controlling the symptoms of space motion sickness.

Nonetheless, the "sensory" conflict explanation of space motion sickness probably has the widest acceptance among experts in the field.

Another explanation of "space motion sickness" may be that loss of the gravity vector per se results in an aberrant sort of input (i.e., over-active, under-active, or a combination of the two) from the vestibular otolith. This sort of explanation assumes that "habituation" within the vestibular apparatus to input occurs over a few days and that gravity sensors simply retune themselves, perhaps due to efferent inputs from the rest of the brain to the vestibular apparatus. This sort of explanation might account for why some individuals seem to be able to tolerate stressful motion environments on Earth and are unable to do so in space.

A third explanation of space motion sickness takes note of the effects of the loss of gravity upon the distribution of body fluids. In the weightless environment, fluid shifts headward. Could this shift produce increased pressure within the calvaruim or increases of fluid (i.e,, endolymph) within the vestibular apparatus? The time course of these fluid changes does not appear to strictly correspond to the symptoms of space motion sickness (see *Biomedical Results from Skylab*).). Nonetheless, this mechanism should be considered. It is possible that this fluid shift contributes to, but does not primarily cause, space motion sickness.

Ongoing Efforts

The research efforts can be divided into:

(a) Ground-based research in man

(b) Ground-based research in animals

(c) Flight experiments with man

(d) Flight experiments with animals

(e) Hardware and technology development.

Ground-based research in man is directed toward evaluation of the mechanisms of space motion sickness. As noted, one fertile source of hypotheses for organizing this investigation is the sensory conflict hypothesis. This work uses centrifuges, rotary chairs and rooms, linear accelerators, horizontal axis rotations, parallel swings, balancing platforms, optokinetic nystagmus drums, cinerama, and devices that can stimulate the semicircular canals and/or the otolith organs. In addition, a wide array of instruments is used to record the effects of these stimulating devices on task performance, musculoskeletal responses, subjective symptoms, the gastrointestinal responses, and general performance. In addition, the effect of overall body fluid shift on vestibular function is measured. Relation between neurophysiologic function and space motion sickness is examined, and various biochemical factors are investigated. Further, there are studies directed toward identifying idiosyncratic psychophysiological or behavioral responses to 0 g that "cause" motion sickness. It is thought that these responses might identify individuals sensitive to space motion sickness. One flawed, but somewhat valuable, model of weightlessness is parabolic flight. A rather wide range of studies are conducted using various antimotion sickness drugs and drug combinations (e.g., amphetamine/scopolamine and promethazine/ephedrine) administered by various routes (e.g., orally, by application to the skin, etc.). One portion of the work attempts to define the best possible combination of drugs for a given individual. An attempt is made to develop standards for selecting individuals who will resist sickness. One program is using a very sophisticated combination of techniques to train individuals to suppress the symptoms of motion sickness. It is clear that this ground-based research has been developed to provide countermeasures to support in-flight experimentation.

The animal experiment is oriented around the same theoretical issues as human work, but capitalizes upon the increased control, instrumentation, and invasive procedures which can be used in animal models. The detailed neuroanatomic and neurophysiologic studies are carried out in order to identify the areas of the central nervous system that play critical roles in the development of space motion sickness. When the areas of brain stem and cerebellum critical to development of an expression of symptoms of motion sickness are identified, the neurochemical and neuropharmacologic receptor characteristics of the critical area can be specified. These data can be used to develop specific drugs to block space motion sickness. One flaw in the current program relates to the lack of involvement of neuropharmacologists in this area of research. Present drugs in use are empirically chosen and the molecular mechanisms by which they produce their therapeutic effect are poorly understood. Other animal studies are in progress that examine critical aspects of the fluid shift hypothesis, and issues relevant to the development of better animal models for flight experimentation. As with the human studies and the animal ground experimentation, the use of parabolic flight to simulate the weightlessness of space flight is marked by rapid shift from the high positive g to a short (measured in seconds) period of free fall followed by a restoration of g. Nonetheless, experiments using this stimulus model of weightlessness may provide some basic information about the mechanisms of vestibular function.

Important Questions

What are the mechanisms by which space and gravity are perceived and integrated across sensory modalities to make normal posture and motion possible on Earth and in space? What elements of these mechanisms are disrupted to produce space motion sickness? Can specific training programs be developed that will prevent the occurrence of space motion sickness? Using biofeedback, the answer to this question appears to be yes. This leads to the question: Can these methods be integrated into crew training, and will they prove effective in the operational environment? Can specific areas of the cerebellum and the brain stem be identified as critical to the development of space motion sickness? If the answer is yes, can a specific biochemical agent be used to block the responses? Can efferent inputs into vestibular apparatus and otoliths be manipulated in a manner that will tune out the mismatched sensory inputs from this source? In addition to these questions, some purely empirical questions in this area are:

(1) Can people resistant to space motion sickness be selected for space flight? (It appears reasonable to eliminate those most susceptible to motion sickness, but apparently this will not eliminate all susceptibles.)

(2) Can the route of administration or modification of combinations of currently-used antimotion sickness drugs result in an effective countermeasure? (All motion sickness medications produce modifications in CNS function and affect peripheral autonomic function.)

All of the foregoing questions are being pursued, although the effort to produce more specific drugs is poorly developed (as is the state-of-the-art). One area of research that does, perhaps, deserve re-evaluation concerns the use of parabolic flight as a model for weightlessness. Given the short period of free fall generated in such flight, and the exposure to 1 g in achieving it, the question should be asked: Is anything relevant to space flight to be learned using this rather expensive model? The justification of this experimental model available to the Life Sciences Advisory Committee has not, to date, been convincing.

Projection

In the immediate future, space motion sickness research should be concerned with the pathophysiologic mechanisms which produce illness, and methods of preventing illness. In the long run, the important issues being investigated have to do with the role of gravity and its perception in the maintenance of posture and achieving motion.

The first practical consequence of this research is likely to be a training method which effectively blocks symptoms. It seems likely that data concerning training plus data from the studies of human sensory function may provide a data base that will be helpful in improving selection procedures. The neurophysiologic research in progress may eventually pay off in far more specific treatments for motion sickness of all sorts. In the immediate future, work manipulating current remedies may make space travelers more comfortable as they adapt to the space environment.

Performance Studies

Rationale

In order to achieve the scientific and industrial potentials of space exploration, exceptional individual and team performances will be required from those who man space vehicles and space stations. The purpose of this research area is to define factors important to the attainment and maintenance of exceptional performance by pilots, engineers, scientists, and artisans participating in the exploration of space or exploitation of the technological opportunities which it affords. In order to maintain such behavior, rational rules are required for the design and distribution of physical space and development of appropriate man/control/machine interfaces within space stations and craft. In addition, it will be important to choose organizational structures for flight mission teams that will assure maximal effectiveness. Individuals who compose such teams must be required to accomplish their mission and purpose. The evaluation of single classes of variables (e.g., social, physiological, personality, and environmental parameters) which influence various performances are well developed areas of inquiry. The findings from such studies have had many industrial as well as aerospace applications. Study of the interaction of these variables as a system which influences team or crew performance outcome is a much less developed area of inquiry. The elaboration of improved methodology for carrying out and analyzing data to support such studies is an important field of inquiry with potential application to space flight as well as better management of crew performance in conventional commercial aircraft. Such studies are particularly important to long-duration space missions. The limited projects supported by NASA Life Sciences in this area address such interactions and, in addition, provide an opportunity to test various methods for maintaining reliable team (small group) performance under conditions which simulate some aspects of space missions.

Status

The basic science effort in the behavioral area is largely funded by the National Science Foundation, the National Institute of Mental Health, and several other Federal institutions. The Department of Defense has a relatively large program in applied behavioral research. Within the area of basic research, only that portion of the NASA in-house program which addresses human biorhythms from a physiological and performance point of view could be considered truly fundamental or basic. Even this portion of the program within NASA is relatively mission-oriented and applied. In fact, NASA's small research program concerning human performance and behavior is a very small part of the national effort. NASA's program is, however, directed toward meeting the specialized needs of NASA. Information from studies of behavior during extended bed rest can contribute to this area of research.

Additional studies, such as those of circadian changes in behavior, require extensive biochemical and physiological sampling to establish correlative relationships between environmental changes and human behavior. For a reasonable NASA program to exist, it must draw heavily on the expertise and resources developed by other sources of funding. In large part, this program has been quite successful in accomplishing this.

For the most part, investigators involved in this program are senior and middle-career. There is considerable variety in the relative productivity of the various senior PI's involved, which varies somewhat inversely with their involvement in applied simulation. This relatively small applied program has not been particularly attractive to new investigators entering the field.

Ongoing Efforts

Research is conducted to develop valid criteria for predicting individual and group performance and adjustment on long and short duration space missions. Various simulations are being carried out to evaluate the potential impact of various space environments. Social and emotional disruptions which are likely to occur under the conditions of these typical space environments will be identified in studies that will involve bed rest, isolation, confinement, motion sickness, and dry runs that simulate other aspects of Shuttle missions. Preflight training procedures will be developed which will prepare space crews for coping with the difficulties associated with space travel. Preliminary studies of the psycho-social aspects of space settlements will be evaluated. Data relevant to selection of crew members is specified.

Questions Being Addressed

(1) To develop operating models for the organization of working space teams to include scientist passengers. The principal question concerns the impact of various organizational and selection strategies upon subsequent performance in preparation for and during space travel.

(2) To perfect techniques for monitoring and predicting performance quality and crew harmony and well-being under space mission conditions.

a. What will be the influence upon role performance of the introduction of women into space crews?

b. What will be the impact of introducing an increased variety of roles upon performance under space mission conditions?

c. What method of simulating space mission conditions provides the most valid and reliable data for predicting and managing performance under actual mission conditions?

d. What group or organizational factors are most relevant for the successful accomplishment of short-term space missions versus long-term space travel?

(3) To develop preventive and corrective procedures for the maintenance of crew psychological well-being and performance quality. Is the Agency's approach to this area of investigation adequate?

With regard to program content, one can identify studies which will provide identification and measurement of individual and social behavioral characteristics most suitable for space travel. In addition, development of selection, training, and correction procedures are in process. The development of physiological and behavioral correlates and the response to the environment of space are being examined by several different investigators. Several of the experimental programs provide the opportunity to test laboratory simulations for validating and developing operational techniques and concepts for utilization in space travel. Critical to whether the aforementioned program content is adequate is the question of whether these efforts are appropriately integrated. Recent efforts at bringing contractors and in-house personnel together to maximize research opportunities by information exchange and integration of effort within this relatively small program are most encouraging.

It is our opinion that present funds and priorities are appropriate in this research area. No large-scale expansion of this effort seems to be indicated at the present time, but one might be necessary should unexpected problems be encountered in the behavioral area in the incorporation of new types of space travelers into the NASA space program. For example, as the number of women, scientists, or space artisans participating in travel or in the industrialization of space increases, new social and behavioral questions may arise which will require new sorts of research tacks.

Projections

It is anticipated that the present program is adequate to support Shuttle and missions currently planned in the Shuttle area. Should industrialization of space or space science require the establishment of space stations (a highly desirable goal within the context of space biological research, for instance), then further studies in this area should be undertaken. If work concerning closed ecological systems in space becomes a major program, then an examination should be initiated of the behavioral and performance characteristics required of humans living in such closed systems. Given the current stage of development of studies of space ecologies, this initiative should await further development and elaboration of the effort. The research in small group studies should continue to be supported, even though its primary orientation is beyond Shuttle, because of the long lead time which will be needed to achieve practically usable information for application to operational space flight requirements.

Preflight Detection of Infectious Disease

Rationale

A number of conditions present in manned space flight, including crowding, stress, and hygienic conditions, may predispose crewmen to infections. Thus, preflight detection of infectious diseases is desirable, as individuals incubating an infectious agent would be at risk and fellow crewmembers would also be at risk. The development of rapid procedures for detection of disease would be of great value for this purpose, as early recognition is essential for operational decisions.

Status

With a wide variety of potential agents of disease, it becomes difficult to design definitive tests. However, recent developments in cellular immunology, as well as rapid procedures for microbial detection, can be exploited.

Ongoing Effort

Cellular immune responses, interferon determinations, and metabolic indicators are being investigated. The most comprehensive program concerns a study of the early blastogenic response of lymphocytes to challenge by infective agents. This program is a joint effort of ARC, JSC, and outside investigators.

Critical Questions

What are the unique conditions of space flight which would predispose crewmen to infections? Can one predict the type of infectious disease that would most likely occur in flight of short and long durations? What type of immunizations are indicated? What kinds of antimicrobials should be considered for flight? What health criteria should be established for selection, e.g., in Shuttle flights? What sort of zoonotic disease detection procedures are necessary to insure the health and viability of experimental animals that go into space?

Adequacy of Current NASA Efforts

The present program is inadequately funded to achieve these goals. Some clinical programs should be considered. A study to determine early immune responses, both cellular and humoral, to infections during the incubation period of different infections in man is ongoing at Baylor University. Such studies should be correlated with others supported by NIH and other agencies. Collaborative funding with these agencies should be considered, and perhaps encouraged, to maximize the effectiveness of this program.

Summary and Recommendations

Practical considerations dictate that preflight tests be made to determine potential risks of infectious disease in flight. Modern advances in our knowledge of cellular and humoral immune mechanisms make it likely that the immune responses can be detected early in the onset of infection. Studies in this area should be pursued. This can only be accomplished with increased funding. Other areas, such as sensitive methods for viral detection, should also be supported.

APPENDIX B

BIOMEDICAL SYSTEMS AND OPERATIONS

BIOMEDICAL SYSTEMS AND OPERATIONS

Medical Selection Criteria

Rationale

This research area is directed toward the medical evaluation of space crews, development of medical selection standards, and valid new predictive techniques. The objective is to select potential crewmen who have the ability to adapt and to work in the space environment. The importance of mission safety and success, and the investment of time and money in the crew, require selecting those without significant defects or predispositions to physical or behavioral disturbances which would impair their efficiency in space flight or during training.

Status

Since the original selection in 1959, there have been 73 astronauts selected through 1970. Forty-three of them have flown successfully. This research area is primarily concerned with the selection and training of flight crews for the Shuttle. In earlier selection programs, the number of individuals involved was small, and much was being learned about human response to the space flight environment with each flight program. Certainly, this knowledge is much firmer at this time, but serious gaps still remain to be resolved for medical selection during the Shuttle era and beyond. The selection criteria which need to be developed appear to fall into two categories. One concerns the identification of degrees of susceptibility to the adverse effects of space flight, such as space motion sickness; the other concerns the assessment of predispositions and conditions associated with the inclusion of broader categories of flight personnel.

Space flight affects vestibular response, circulatory function, fluid and electrolyte balance, skeletal and muscular integrity, and red cell mass. Much remains to be learned about the physiological mechanisms involved, countermeasures, and prognostication of these changes.

Given the anticipated duration of Shuttle flights (i.e., no longer than 30 days), most of the documented effects of space travel will not produce obvious health hazards. One possible exception to this sanguine prediction is space motion sickness. This has afflicted about 50 percent of past crewmembers and will have its maximal impact on short missions (i.e., ten days or less) that will characterize early Shuttle flights. In the past, this has only minimally disturbed the crewmembers' manifest performance output, a finding which seemingly reflects favorably on the effectiveness of the selection and training procedures used, but it must be recalled that previous crews have, in large part, been composed of qualified, experienced aviators who were highly motivated for their mission duties. The scientists aboard Shuttle will be required to perform high order intellectual tasks. Furthermore, the motivation that drives these scientists will be different from that previously observed in astronauts performing technical tasks. Space motion sickness may very well disrupt the mission accomplishment which requires such high level performance.

The Shuttle era emphasizes the challenge to develop new, improved procedures to identify those susceptible to space motion sickness. Improved methods must be developed to identify levels of susceptibility, not only to space motion sickness, but to all of the known effects of space flight in these individuals. Male/female differences must be scientifically established, and latent pathology, such as coronary disease and its risk factors, must be identified and quantitated. Finally, provision should be made for adequate retrospective analyses to evaluate the selection techniques already used, and for long term follow-up to allow newly developed techniques to be tested on veteran flight crews whose flight responses are already known.

Ongoing Effort

The following studies are being conducted at the Johnson Space Center:

1. Brandeis University is under contract to develop vestibular selection criteria. This study proposes to expose subjects to various motion sickness-producing devices. Optokinetic studies have been emphasized to date. The study also calls for a literature review and the administration of psychodynamic personality inventories to try to relate these to susceptibility to motion sicknesss.

2. Long-term analysis of medical selection of astronauts and crews. This is really the longitudinal study, although much of the emphasis in the writeup is on the recent selection program. It calls for the analysis of data from all flight programs and a continuing flow of information from this longitudinal study to future flights and to ground-based medicine.

3. This task, titled "Astronaut Motion Sickness Susceptibility," is being done in-house at JSC. The investigators are attempting to develop a battery of vestibular tests which will discriminate between individuals who will develop space motion sickness and those who will not. It will be tested on astronauts who have flown and thus have a known positive or negative space motion sickness history.

The following tasks are being conducted at the Ames Research Center:

1. Two tasks have been combined, titled "The Medical Selection of Space Shuttle Passengers and Human Tolerance to $+G_z$ Acceleration." These tasks are legitimately combined, for they use human bedrest studies as their basis. This is a series of studies on both males and females of progressively older age groups. Following bed rest, the subjects are exposed to $+G_z$ acceleration. To date, it has been found that lower body negative pressure responses do not show age differences, but do show sex differences in the 35 to 45 age group for the most likely Shuttle reentry profile.

2. Echocardiography in the selection of Shuttle passengers. Studies have been performed on the heart size and shape during LBNP pre- and post-bed rest It has been noted that following bedrest there is up to a 50 percent reduction in end diastolic volume in the left ventricle by this method. During LBNP, it was particularly noted that women have almost twice the reduction in end diastolic volume with LBNP following bedrest. This finding accounts for the difference between men and women in post bedrest acceleration tolerance. It is felt that

20 to 50 percent of the persons who would be passengers will have difficulty with the reentry profile of the Shuttle unless they are protected with G suits.

Critical Questions

1. Is there any method of selecting those individuals who are not sensitive to space motion sickness prior to space flight?
2. Who is more prone to orthostatic intolerance generally, and under the effects of $+G_z$?
3. Are there age and sex differences in orthostatic intolerance?
4. Are there methods useful in selection relating to the other physiologic changes resulting from space flight?
5. What are the best evaluation techniques for determining latent disease involving the organs of most concern in space flight?

Adequacy of NASA Effort

The overall program seems to be addressing the critical medical selection problems with the use of in-house investigators. This seems to be sensible in view of the nature of the questions raised here, and there is adequate in-house capability to address these. There are areas where outside support, at least in terms of information sharing if not in actual research, would be valuable as we look for better noninvasive techniques for evaluating future disease risks. In addition to the use of stress testing and electrocardiography to assess coronary status, other major risk factors should be evaluated, such as family history, smoking, obesity, lipid levels and types, uric acid, and stress levels. Most of the efforts relating to vestibular selection criteria are focusing on the same techniques previously used, which have been of little predictive value. Some unique aspects are being investigated, but apparently little use is made of past flight crews whose motion sickness responses to space flight are known. The value of data generated in parabolic flight is doubtful.

Funding appears adequate for the tasks being done. More emphasis should be placed on longitudinal studies to bring the information up to date.

Vestibular selection criteria studies underway should be improved. Fresh, innovative concepts must be sought.

Future Projections

The establishment of medical selection standards must be regarded as a continuing process involving the development of evaluation techniques, prospective evaluation utilizing simulation, and retrospective analyses of flight data. Only through this process will it be possible to safely broaden the composition of future flight personnel to include greater age ranges, more varied backgrounds and work capabilities, and very probably an expanding list of specific disease states.

Summary

The first selection of space crewmen since 1970 was completed in the past year. It was based on a set of standards specifically designed and developed for Shuttle crew composition. Studies are underway to answer some of the critical questions regarding medical selection. These should be continued, but early, helpful answers to the problem of selecting those not sensitive to motion sickness do not now appear to be in prospect.

Recommendations

1. Recommend re-evaluation of the vestibular selection efforts.
2. More emphasis should be placed on identifying those changes associated with space flight that might be amenable to testing in selection programs, i.e., orthostatic tolerance, hydroxyproline levels, and red cell characteristics.
3. Highly recommend the use of a broader cardiac risk profile in attempting to identify those individuals most predisposed to the development of coronary heart disease.

Definition of Physiological Design Requirements

Rationale

This research area is concerned with a range of physiological stressors on the body: thermal regulation, respiration, radiation, and chemical toxicity. The involvement of older astronauts, women astronauts, new spacecraft materials, and longer missions all contribute to the need for continued investigation of physiological design requirements.

Status

A number of research projects have been ongoing in this area, and several excellent compendia and literature surveys have been commissioned by NASA (e.g., the multi-volume NASA CR1205, November 1968 by Lovelace Foundation). Perhaps the latter needs updating.

Ongoing Effort

A modest research program is equally divided between in-house (JSC) and university research. One NASA supported project in this area is a collaborative effort with Brooks AFB. The Air Force, primarily Brooks and Wright-Patterson AFB, supports research in many of these areas.

Critical Questions

Primary questions being addressed concern:

1. effect of zero gravity, age, and sex on thermoregulation
2. effects of these factors on nitrogen bubble formation at low pressures
3. the requirement for light in or near the ultraviolet range for sustained manned space flight

4. continued appraisal of cabin and pressure suit gas requirements
5. toxicity of pyrolysis products of spacecraft materials
6. design of fire resistant clothing
7. toxicity of exposure to spacecraft materials and toxicity standards.

Adequacy of Current NASA Efforts

The current program and funding levels are quite modest. There is no evidence of life sciences considerations being factored together with reliability analyses such as fault trees, presently used to assess potential hazards in nuclear plants.

Further, in developing standards for factors such as toxicity, it seems that some cost-benefit analysis might be used. What are the costs of strict standards?

Teleoperator Technology

Rationale

A teleoperator is a robotic device having video and/or other sensors, manipulator arms, and some mobility capability, which is remotely controlled over a telecommunication channel by a human operator. This human operator can be a direct in-the-loop controller who observes a video display of the teleoperator and, with a joystick or analog device, continuously controls the position of a teleoperator vehicle, its arms, or its sensor orientation. Alternatively, the teleoperator can employ a computer, endowed with a modicum of "artificial intelligence," which is capable of executing simple control functions automatically through local force or proximity sensing; in this case, the remote human operator shares and trades control with the computer.

Status

Relatively crude teleoperators were developed in the 1940's and 1950's for nuclear hot laboratories and some undersea vehicles. The American Surveyor was our first space teleoperator, the Soviet Lunokhod the most sophisticated planetary roving teleoperator. Considering the potential of teleoperators for space applications, there has been only miniscule funding. The apparent reason is the lack of any mission which really required such a device (the Shuttle manipulators are the first major expenditure). The man-machine sensing and control problems are clearly the most important and demanding problems.

Ongoing Effort

JPL, ARC, and MSFC have had relatively small research projects in this area. AEC and ONR have supported some research. More recently, there has been a tremendous surge of interest in manufacturing applications of robotics, not teleoperators per se, but computer-controlled machining and assembly devices. In the last three years, there has also been a new interest in commercial undersea teleoperators for oil and mineral exploration and recovery.

Critical Questions

1. When should teleoperators be special purpose remotely controlled machines (e.g., space beam builders) and when should they be general purpose devices?
2. When should the form be anthromorphic, and when not?
3. When should the "hand" be general purpose, and when should various special purpose tools be attachable and detachable at the wrist?
4. How important is teletactile sensing in relation to television; what are appropriate ways to display such signals to the operator; what various forms does it take?
5. How can "teleproprioception" be maintained so that the operator does not lose track of the teleoperator's configuration and relation to environmental objects?
6. What does transmission time-delay do to man's ability to control a teleoperator?
7. In the event of limited bandwidth video channel, what is the proper trade-off between frame rate and resolution?
8. How can a computer help, either at the remote (teleoperator) location or at the local (human operator) location?
9. What does it mean for a human operator to share and trade control with a computer, or to become a supervisor of a lower level (computer) intelligence?
10. What mix of analogic and symbolic language is appropriate for the human operator to use?
11. How do you evaluate a teleoperator's performance (motor skill, intelligence)?

These questions are beginning to be answered. Younger scientists, especially computer scientists, have been attracted to this area. However, there are few life or behavioral scientists participating in this work.

Summary and Recommendations

1. Make the potential of teleoperators better known within NASA.
2. Clarify the life sciences aspects of teleoperator research.
3. Increase funding significantly.

Man-Machine Engineering Requirements for Data and Functional Interfaces

Rationale

This research area covers a broad effort to improve the discipline and art of designing man-machine interfaces; displays, controls, general spacecraft interior layout, work routines, crew selection, size, and staffing techniques for collecting human performance data, simulating missions for habitability, stress, and control studies.

Status

Much is known about many man-machine factors, but the discipline is primitive.

Critical Questions

There may be no "critical" questions here. Instead, there are many interacting concerns which deserve continuing support, provided the experimental questions are well formulated.

Adequacy of Current NASA Effort

The current projects and level of funding appear adequate. However, some projects do raise questions. These projects include:

1. Development of a six degree-of-freedom hand controller. None has been satisfactory thus far, though MSFC has supported some such work. Funding seems adequate here, though the task is more difficult than one might first guess.

2. Automated crew station design. These investigators should maintain close contact with ongoing developments of computer-aided techniques for layout and design in the aircraft and automotive manufacturing areas.

3. Dynamic anthropometric measurement. This is a reasonable need with low level funding. (Investigators should know about Swedish Sel-Spot and similar instruments currently used in rehabilitation engineering.)

4. Advanced display requirements. This is a very general need, and if well executed, the research can be quite helpful, especially where computer based displays are of primary concern.

5. Remotely piloted vehicles. This is a transfer of technology, or liaison effort, which seems appropriate.

Summary and Recommendations

Since this project is primarily to develop engineering technology and techniques, it will require close review and coordination of specific projects and questions investigators seek to answer.

Advanced Extravehicular Systems

Rationale

Long-term missions involving Shuttle and future space construction and maintenance by men during extravehicular activity (EVA) pose increased demands on garment and life support equipment design. Pressure suits will have to be more flexible and allow greater dexterity and longer periods of EVA in comfort. Even as teleoperators and other forms of automation replace men for many inspection and manipulation and control tasks, astronauts in EVA will have to be available for back-up, maintenance and repair, etc.

Status

Space suits and life support systems have made impressive strides. A reputable group at Ames Research Center has continued design effort in this area. Eight to ten PSI suits are now in development. However, metabolic costs for EVA have always been high.

Ongoing Effort

There is probably little sustained R&D in this area other than small groups at ARC and JSC.

Critical Questions for EVA Suit Development

1. What are the trade-offs between increasing suit pressure, with attendant mobility and reliability problems, versus continuing lower pressures, with attendant nitrogen bubble and decompression problems?
2. How should heat sinks for liquid cooled garments be improved?
3. How best to develop a regenerable life support system (CO_2 and thermal control)?
4. How can size of supporting hardware components be reduced?
5. How can scratch resistance of visors be improved?
6. How can arm/leg/hand mobility be enhanced?
7. What is the basis of high metabolic cost of EVA?
   a. effort exerted in postural control
   b. mechanical work against the suit
   c. mechanical work against external objects
   d. anxiety

Adequacy of NASA Efforts

The program seems to be adequate in scope and has qualified in-house and contract investigators involved.

Future Projections

Continued need for more reliable, comfortable, and mobile EVA systems. Possible integration of EVA systems with special hand tools, power tools, etc.

Summary and Recommendations

1. Clarify design trade-offs, especially those involved in increasing suit pressure.
2. Determine the basis of high metabolic cost of EVA, and the implications of this for design of EVA task.

The Monitoring and Maintenance of Crew Health and Clinical Medicine Crew Support

Rationale

The thrust of these research areas is to provide for the maintenance of the health of both Shuttle crewmen and passengers. The tasks of those involved in Shuttle flights will require a high level of alertness, and thus, a high state of health. This state of health must be defined and monitored and access to quality health care must be available in flight.

Status

Since the beginning of manned space flight, NASA has provided the capability to monitor physiological responses to the environment. It has also provided some medical care ranging from voice communication through primitive medical kits to the elaborate inflight medical system provided on Skylab. Through the flight programs to date, these efforts have been adequate to maintain superb performance and to handle the inflight medical problems encountered. The hiatus which began with the conclusion of the Skylab program should allow time to better define the physiologic state-of-man in the flight environment and on his return to Earth. There are definite physiological changes involved in adapting to the weightless state. A more difficult reversal of these changes occurs on readapting to the 1 g state on return to Earth. Health has been defined in the RFP, as in the dictionary, as "the state of the organism when it functions optimally without evidence of disease or abnormality." The emphasis in any preventive program is on maintenance of crew health in relation to the space environment. The data from previous flight programs, Skylab in particular, should allow us to define the appropriate physiological adaptation to the space environment more accurately. This information has led to the development of more refined procedures and equipment for the monitoring of inflight health status, the identification of any changes which are detrimental to health, and the determination of requirements for countermeasures. Some of the tasks in this program will require inflight experiments to test and prove the validity of selected procedures and equipment. Early bedrest studies led to the hypothesis that there would be loss of work capacity after man's exposure to weightlessness. As a result of this concern, exercise response was evaluated both inflight and postflight in the Gemini program. With longer periods of flight, exercise has been looked upon as a necessary countermeasure and thus the direction of interest has changed as a result of our inflight findings. The crew got psychological help from the exercise and they felt, as did the medical team, that it helped their recovery postflight. Thus, there is a great desire to continue to recommend increasing amounts of exercise inflight. However, it is hard to collect good statistical data on the effect of given amounts of exercise on various physiological variables. Exercise is being viewed as a countermeasure to the effects of weightlessness on various body systems and the amount and mode of exercise remains a question.

Ongoing Effort

The following tasks are being conducted at JSC and ARC:

1. The support of the cardiopulmonary laboratory is primarily directed toward the development of cardiopulmonary selection criteria, development of noninvasive techniques, and an ongoing evaluation of the risk of coronary heart disease in crewmen, potential crewmen, and NASA executives.
2. There are three tasks on exercise response:
   a. Coleman, at the University of Houston at Clear Lake City, is evaluating the exercise response characteristics of potential Shuttle passengers and subjects similar to potential Shuttle passengers. Stress tests are done before and after various exercise programs in trying to determine the value of particular exercise programs for various activity levels.
   b. Luft, at the Lovelace Clinic, is evaluating the effect of exercise training and physical fitness on orthostatic tolerance. He believes that leg muscle exercise in particular, and a high level of physical fitness in general, may be counterproductive to the maintenance of orthostatic tolerance because it may result in larger capillary beds in which the blood can pool.
   c. One project is concerned with the development of Shuttle exercise equipment based on some of the information from the above programs.
3. Greanleaf and coworkers are evaluating fluid and electrolyte shifts on $+G_z$ acceleration tolerance. A portion of this project is concerned with determining optimal isometric test cycles to prolong positive $+G_z$ tolerance during centrifugation and determining an optimal exercise training program to facilitate maximal tolerance.
4. Lower body negative pressure (LBNP) is being evaluated as a substitute for exercise testing protocols. Various age groups are being tested on treadmill and bicycle ergometry protocols and on LBNP to see what negative pressure level is necessary to produce heart rates to equal 80 to 90 percent of maximal treadmill or ergometer response.
5. The task titled "Advanced Health Monitoring Techniques" is really a use of systems analysis by General Electric to help define health in space through analysis of the Skylab data so that a system for determining deviations from the defined normal can then be developed.

6. A project for development of an anti-G cardiovascular countermeasure garment. It is expected that the reentry G profile will be 1.5 $+G_z$ for 20 minutes after the crew has been weightless. The basic question being asked is whether to use a capstan or a bladder suit. A sizable amount of data should already exist in this area.

7. There are two tasks which are really for purchasing in-house equipment for various laboratories.

8. A hardware development program for a cardiopulmonary measurement system which could be utilized in an inflight experiment.

9. The only task addressed to nutrition in space flight is an MIT investigation of protein and amino acids in stressful situations.

10. Another hardware development project is designing an inflight cardiopulmonary recording system which could become a miniaturized crew health monitor system.

11. A miniature laboratory system for use in space flight and ground-based health care utilizes a centrifugal fast analyzer adapted for micro samples and small amounts of completely contained reagents. This is a modification of the GeMSAEC analyzer. It would allow multiple biochemical determinations in flight.

12. Specific ion electrodes developed by Orion for calcium, potassium, and sodium, adapted for space flight use.

13. A project with the Boeing Corporation to develop medical requirements for the Space Shuttle mission. This is not a research task.

14. The effects of weightlessness and gravity on pulmonary function are the subject of a grant to the University of California at San Diego Medical School. The work done to date has led to the possibility of developing a flight experiment.

15. A project on the effects of fluid and electrolyte shifts on metabolism and $+G_z$ acceleration tolerance. Aside from the exercise portion previously mentioned, it includes efforts to evaluate heat acclimatization to improve LBNP responses and $+G_z$ tolerance in both men and women. German aviation medicine data from World War II should be of value here.

16. Two projects are concerned with drug interactions in manned space flight. One is investigating the effect of the anti-motion sickness drugs on certain biochemical parameters. The other proposes to use bed rest as an analog for space flight to look at the disposition of various drugs which might be used in flight.

Critical Questions

1. What is normal physiological function and performance "in space?" What is "normal" health in space flight?

2. What physiological parameters should be monitored on the crew and passengers in the Shuttle?

3. What are expected medical problems requiring diagnosis and treatment in Shuttle flight?
4. What countermeasures are necessary in view of our knowledge to date?
5. What evaluation and diagnostic equipment can be made available in time for Shuttle flight use?
6. Can exercise be a countermeasure to some of the body system effects seen following exposure to weightlessness? If so, what is the type and amount of exercise necessary?
7. Can the relationship of exercise to deconditioning in weightlessness be determined?
8. What is the relationship of exercise to adaptation in 0 g and readaptation to 1 g? Is it helpful in either or both instances?
9. What is the best exercise device for flight use?
10. What is the best exercise protocol for maintaining the health of the crewmen and to prevent muscle loss and other system changes?
11. Is exercise, particularly involving the legs, a detriment to orthostatic tolerance?
12. Is LBNP a suitable replacement for exercise in evaluating the crew pre-flight and conditioning the crew inflight?

Adequacy of NASA Efforts

The program seems to be adequate in scope. Both in-house and contract investigators involved are well qualified.

The funding seems adequate to bring the data and the equipment to a state of readiness in the needed time frame. A few tasks, such as the University of Houston task on exercise, seem markedly under funded.

It appears that the proper priorities have been placed for 14 to 17 day flights. The concern about the importance of pulmonary function changes in space flight may be excessive, judging from flight data obtained so far.

Future Projections

This area will continue to be of importance as long as man flies in space. Due to the small size of flight crews, every opportunity should be taken to obtain information which will add to the data base for the safety of future flight crews. As longer flight periods are considered for future programs, it will be important to know the role of exercise as a countermeasure. It also appears necessary to determine early whether exercise is indeed a detriment to orthostatic tolerance, and if so, whether lower body negative pressure can correct this deficit so that the other benefits of exercise can be maintained.

Summary and Recommendations

This research is well directed in attempting to define the state of health in the 1 g and the 0 g environment, and providing the information and the equipment (countermeasures) to maintain that state-of-health in both instances.

Some have stated that the only preventive measures used to date have been with drugs and exercise. Certainly diet has been used as a preventive measure, but there is a lack of balance in the program. Only one task addresses nutritional considerations, and that is limited to proteins and amino acids. Nutrition is an important part of an adquate preventive medicine program, particularly for longer duration flights.

The following additional recommendations apply to the exercise program:

1. Early efforts should be made to find the role of exercise in decreasing orthostatic intolerance.
2. An exercise device and protocol under medical control should be developed for inflight use to maintain the health of the crew and to prevent muscle loss and as many of the other physiologic changes as possible.
3. Consideration should be given to developing experimental protocols to define the relationship between exercise and deconditioning, and exercise and adaptation and readaptation in the weightless environment.
4. Assure efforts to integrate the activities of those responsible for crew health with those carrying out research so that research answers may be quickly applied to crew health.

Aerospace Medicine and Safety

Rationale

This research category consists of three program areas:

A. *Flight Management Systems*. More people are being carried by commercial aircraft; constraints imposed due to speed, noise, and all-weather operations are becoming more demanding, and computer and sensor technology has advanced. Therefore, a greater degree of automation is being introduced, and the role of the commercial pilot is changing from that of a continuous in-the-loop controller to that of a manager of many computer-based systems. While outwardly his task is easier (he is seemingly upgraded to a more dignified position) there is a danger that in an emergency he will not be able to cope with the complexity of these new systems and cannot effectively diagnose faults and take over control.

This category of research is crucial in that it affects the safety of the whole future generation of air travelers.

B. *Human Factors in Aviation Safety*. This research is primarily an effort to gather information about human errors in actual aviation operations, and to associate this with simulator and other studies. No such data base presently exists with anything approaching an adequate degree of technical detail and reliability.

C. *Simulation Technology for Aeronautics*. Tremendous progress has been made recently in moving-base flight simulators for training and research. All the major airlines now train their pilots mainly on simulators. Pilot trainees can experience various emergency situations and develop fast appropriate responses. Such simulators have also provided a basis for experimental research in motion perception, visual-vestibular interaction, including motion sickness, pilot opinion models for rating aircraft handling qualities, pilot workload, etc. Continuing developments in computers and visual displays promise continued economic, training, and research payoff in this direction.

Status

While a great deal of engineering know-how is available within NASA, the military, and industry, a disciplinary approach to dealing with the human organism as a pilot/decision-maker is in its infancy. At this time, we can predict human response in very simple piloting situations. But as the pilot's role changes, the discipline of man-machine systems must adapt.

Ongoing Effort

NASA (primarily at Ames) has pioneered in these areas, and has consistently and self-consciously supported university and discipline-developing research.

Critical Questions

Some larger questions are:

1. What are the appropriate roles for computers and for man?
2. When, if ever, does flexibility and sophistication reach a point of diminishing returns?
3. What causes pilot error?
4. How good is the aircrew at detecting system failure?
5. How can the computer assist in such failure detection?
6. How can the pilot better anticipate and prevent pilot error?
7. Can we create real stress situations in a simulator?

These questions are being addressed. A number of younger scientists are being attracted to this area. They see similar problems ahead in other areas where large amounts of capital are concentrated, where there is high risk to the public, where computers are taking on more and more control responsibility, and where the human's role is becoming more complex and even ambiguous (e.g., chemical plants, nuclear reactors).

Adequacy of Current NASA Efforts

This program is appropriate and seemingly well managed. All these research areas deserve continued growth.

Funding is inappropriately small in relationship to the size of the human risk and disciplinary (life science) payoff.

Priorities are proper.

Future Projections

The life sciences (man-machine interface) problems, by comparison to the materials, electronics and physical science problems, will become more critical with time rather than less because the state of our man-machine discipline is so primitive compared to its physical engineering counterparts.

As air traffic increases around certain metropolitan areas, problems of navigation (reading maps) and communication (voice) have placed increasing workload on the pilot. There will be increased use of computer-based displays (integrated graphic and alphanumeric) and communications between ground-based and airborne computers.

Recommendations

1. Increased funding, with the aim of clarifying the clear advantages and the potential pitfalls of automation, especially with respect to relative roles of man and computer, and the implied workload on each in the event of sudden transients (in emergencies).
2. Promotion of increased cooperation, not only with Air Force and FAA, but also with industry in man-computer cooperation, human reliability and failure assessment, and human workload studies.

Advanced Life Support Systems and CELSS

Rationale

Life support system technology provides the basis for the development of equipment and procedures which supply the human occupants of a vehicle or space station with the following:

- Food
- Potable water

- Breathable atmosphere
- Waste disposal
- Personal hygiene
- Safety from identifiable hazards
- Reasonable comfort.

Relevant technology also includes the necessary instrumentation and control systems which monitor and integrate the functional performance of associated sub-systems and provide for stable operation of these sub-systems.

Life support systems are considered to be "open" when food, water, and oxygen in the breathable atmosphere are not regenerated; i.e., these components are stored onboard at launch and expended without an attempt to regenerate them aboard the spacecraft (although they might be resupplied from Earth, when practical). In completely closed systems, carbon, water, minerals in waste materials, and metabolic carbon dioxide are regenerated into food, potable water, and atmosphere components. Partially closed systems provide for the regeneration of some, but not all, of these vital input materials; the rest are expended from onboard storage or resupplied from Earth.

Status

Thus far in the U.S. space effort, the manned missions have not required regeneration of food, oxygen, or water. Therefore, only open life support systems have been employed on these missions. The scope of these missions, in terms of the duration and number of vehicle occupants, permitted the exclusive use of consumables that were stored onboard the spacecraft. One slight exception was the longer-duration Skylab missions on which a "regenerable" molecular sieve subsystem was used to control metabolic carbon dioxide buildup in the spacecraft breathing atmosphere. However, the carbon dioxide was *not* converted into oxygen to resupply that component in the atmosphere. Since the Space Shuttle and Spacelab missions are similarly short in duration, they will not require closed life support systems technology.

For logistical reasons, it can be expected that long-duration missions involving a relatively large number of people in a space habitat will require completely, or at least partially, closed life support systems. For these types of missions, which might develop beyond the Shuttle era, it is quite likely that complete dependence upon the use of expendables, instead of regeneration, would be prohibitively costly with respect to transportation requirements. Therefore, although NASA's technology-development efforts have been limited to open or partially-closed life support systems, current planning efforts by the Office of Life Sciences include consideration of technology requirements and research strategies for completely closed life support systems. Recent analyses which relate to these planning efforts have shown that the present data base is significantly more advanced for physicochemical technology applicable to life support systems closure processes than for relevant biological technology. This stems principally from the orientation of NASA-sponsored life support systems R&D (for partially closed systems) over the past decade and a half. One of the most critical voids in the data base is information on the effects of non-terrestrial environmental conditions (non-air atmospheres, low gravity, etc.) on terrestrial biological systems that might be reasonable candidates for closure processes (i.e., regeneration techniques) in a closed life support system.

Ongoing Effort

A. *NASA-Sponsored Efforts*: Technology development efforts sponsored by NASA in the field of advanced life support systems include water reclamation, carbon dioxide concentrators, oxygen generation from carbon dioxide, food preservation and storage, trace-contaminant analysis and control, waste oxidation, nitrogen generation to resupply atmosphere, and biological components for closed life support systems (new exploratory effort, initiated in FY 1978). The principal emphasis is on physicochemical processes, including alternatives routes, in most cases.

Specific research areas for fiscal year 1978 are as follows:

1. Biowaste Monitoring System (to support Shuttle life sciences experiments);
2. Development of Water Quality Standards (for reclaimed water from urine and wash water);
3. Spacecraft Disinfectant and Cleansing Agent Development;
4. Advanced Food Packaging and Intermediate-Moisture Foods;
5. Food-Heating Supporting Technology;
6. Engineering and Food Technology Evaluation of Advanced Space Food Systems (preservation and storage for open systems);
7. Compression of Rehydratable Vegetables and Cereals;
8. Electrochemical Water Quality Monitor;
9. In-Situ Calibrated Hydrogen Sensor System;
10. Wet-Oxidation Waste Reclamation (physicochemical processing of mixed-waste slurries);
11. Urine-Reclamation Subsystem;
12. Nitrogen-Generator Development;
13. Electrochemical Carbon Dioxide Concentrator;
14. Trace-Contaminant Control;
15. Solid-Electrolyte Oxygen Regeneration System;
16. Reverse-Osmosis Membrane Development and Characterization;

17. CELSS Maintenance Instrumentation (fault diagnosis, correction, and prediction);
18. Miniature Gas Analysis Systems for Use During Space Flight;
19. Biological Life Support System Development (concept analysis);
20. Waste Management for Biological Life Support Systems;
21. Application Study for a Flyable Mass Spectrometer Facility (new-generation "focal plane" MS);
22. Demonstration of Feasibility of a Miniaturized Focal Plane Mass Spectrometer Facility Using Electro-Optical Ion Detection;
23. Bioregenerative Life Support Systems (aquatic ecosystems);
24. The Bosch Process (for oxygen regeneration from carbon dioxide);
25. Catalysts for the Electrochemical Generation of Oxygen;
26. Monitoring Spacecraft Atmospheres by Laser Absorption Spectroscopy;
27. Electrochemical Carbon Dioxide Concentration Using Molten Salt Electrolytes;
28. Transport of Trace Contaminants Through Porous Media;
29. A Research Program in Bioenvironmental Systems.

B. *Other Efforts*: In the United States, virtually all of the life support systems technology applicable to space missions is and has been supported by NASA. The U.S. Navy has sponsored extensive work on contaminant control systems and atmosphere control systems for submarines. However, this work has not been of technology-pacing significance for manned spacecraft applications, and it has not emphasized system closure.

Interestingly enough, a significant number of the closed-chamber agriculture studies, in phytotron and biotron facilities in the U.S., which have been sponsored principally by USDA, the National Science Foundation, and industry, appear to have important potential relevance to closed-ecological life support systems (CELSS) for future manned space missions. However, this work was not specifically oriented toward spacecraft CELSS applications.

For the past five to ten years, biological researchers in the USSR have been conducting closed-ecosystem studies specifically oriented toward CELSS applications. This work has been reported in the "open" literature (e.g., Gitel'zon, I.I., *et al.*, "Problems in Space Biology, Vol. 28, Experimental Ecological Systems Including Man," Nauka Press, Moscow, 1975; NASA Technical Translation F-16993). Results of this work clearly demonstrate that the Soviet Union has progressed further than the United States in CELSS technology exploration, experience, and demonstration of closure concepts.

Recommendations

This program area has particularly difficult planning problems with respect to the anticipation of applicational requirements and the formulation of technology-development priorities. This derives principally from the fact that there are no specific plans for long-duration manned missions that would clearly require partially or completely closed life support systems. The problem associated with establishing a scientific orientation for the program appears to have the following principal components, all of which require speculation and prognostication:

1. Estimating the likely lead-times that would be *available* for the final development of systems to flight readiness, should a manned mission become officially established which requires advanced life support systems;

2. Estimating the total lead-time that would be *required* for the completion of all systems development efforts which are necessary to provide mission-ready systems capability;

3. Based on the difference between the lead-time estimated in (1) and (2) above, identify the crucial long lead-time technology development initiatives that must be pursued and can be justified to meet anticipated applicational and readiness requirements.

All of the above decision-making components must account for the spectrum of different systems capabilities that might be required to satisfy various types of mission applications (depending upon the duration of the mission, the number of occupants in space habitats, the remoteness of the vehicle or space station from Earth, the gravity and the atmosphere environment in which the system must operate, etc.).

Therefore, recognizing these planning complexities, the following recommendations have been formulated to assist NASA in orienting and prioritizing its technology-development efforts in this program area:

- NASA must emphasize a very flexible and utilitarian R&D program in this area. More specifically, efforts should be directed toward system and subsystem technology, including demonstration equipment, which has the greatest potential for general application, irrespective of subtle variations in mission characteristics. For example, emphasis on partially closed life support systems, and particularly the development of optimum approaches to closure functions and stability (as well as the reduction of weight, volume and power requirements), would probably provide the greatest general utility potential.

- Because of the need to demonstrate functional reliability and safety of innovative systems before they are accepted for flight use, maximum use of Space Shuttle and Spacelab missions should be pursued for the testing and evaluation of closure subsystems under actual space conditions, where ground simulation will not provide adequate experience. Similarly, space experiments onboard Shuttle-based missions should be conducted to determine the effects of weightlessness on any biological processes which show promise as optimum approaches to closure. However, in many cases, this will require much longer exposure times than presently planned Shuttle-Spacelab missions can support. Therefore, a determined effort must be made to establish missions that will support these longer-term weightlessness experiments, and particularly multigeneration studies.

- Although the current Advanced Life Support Systems research areas do include some food technology studies, principally on food preservation and storage, one of the most important aspects of food planning for manned space flight, i.e., food acceptability criteria and approaches for meeting these criteria, requires greater emphasis.

Clearly, within the scope of these general recommendations, there are many research options that would be relevant and potentially important. Table B-1 provides an illustrative listing of problem areas which are particularly relevant to research planning for advanced life support systems. To assist NASA in this difficult planning task, the following specific recommendations are offered. Research initiatives that should be emphasized during the early (e.g., first five years) phase of effort include:

1. Define specific applicational goals and technological objectives for advancements in life support systems capability as the basis for a justifiable rationale for the commitment of NASA's resources in this area;

2. Given the results of (1) above, establish a set of clear scientific objectives and prioritize these with respect to their relative roles in satisfying the major applicational goals;

3. For each of the higher-priority scientific objectives identified in (2) above, determine the most appropriate role for NASA's Life Sciences Directorate in the achievement of these objectives (either as sponsor, directly, or coordinator of sponsorship by other agencies);

4. Initiate highest-priority research, within realistic budgetary constraints, with the NASA Life Sciences Directorate providing overall program management and sponsoring or coordinating extra-NASA sponsorship, as appropriate, to achieve specific objectives of the scientific effort;

5. Without prejudging the optimum technical orientation of these initial research efforts (the eventual results of [1] and [2] above), it is recommended that primary emphasis be placed on investigating and producing an adequate data base on functional performance characteristics of a reasonable variety of alternative processes (biological and physicochemical approaches) to achieve key regeneration functions (food production, air revitalization, water reclamation, and waste management);

6. The results of these early investigations should be carefully reviewed by a competent, multidisciplinary council, iteratively, and evaluated frequently to provide feedback control and "fine tuning" of the orientation of the scientific and engineering efforts toward the processes and design approaches that offer best prospects for achieving the applicational goals of (1) above;

7. A very dedicated management effort should be directed toward identifying and effectively pursuing opportunities for valuable relevant experimentation on Spacelab missions (e.g., effects of non-terrestrial environmental conditions on the functional performance of alternative processing approaches).

Table B-1

Relevant Areas of Technology

- DIET PLANNING
  - Human nutritional requirements
  - Food and food-source selection criteria
  - Nutritional equivalency of various food sources
  - Physiological and psychological acceptability aspects of non-conventional diets and food sources
- FOOD PROCESSING
  - New concepts for preparation processing, storage and distribution to reduce equipment and resources requirements
  - Improved preservation and packaging of earth-produced foods.
- FOOD SYNTHESIS APPLICATION
  - Acceptable microbiological sources and production methodology
  - Acceptable chemical production of protein and carbohydrates
- AQUACULTURE APPLICATIONS
  - Food-producing ecologies based on waste-conversion
  - High-yield, high-nutrition plant and animal production and harvesting
- LAND AGRICULTURE APPLICATIONS
  - Plant culture and physiology in space environments
  - Animal culture, nutrition and physiology in space environments
  - New concepts to reduce spatial requirements
  - New equipment concepts for cultivation and harvesting
- WASTE CONVERSION AND RESOURCE RECOVERY
  - Physicochemical processes, particularly mineral separation and recovery
  - Microbiological processes
  - Auxiliary non-food products from wastes (e.g., paper and tools)
- SYSTEM STABILITY AND SAFETY
  - Closed-system ecology
  - Materials selection
  - Chemical analysis and control of contaminants and toxicants
  - Compartmentalization design concepts
  - Atmosphere selection
  - Selection of gravitational environment
  - Radiation shielding requirements and methodology
  - Health-care facilities requirements

For long-term (first decade) research activity, it appears appropriate to emphasize the construction, testing, and performance-evaluation of demonstration systems that are designed to provide the most generally applicable and most promising approach to regenerative processing, as defined in item (1) of the early-phase recommendations listed above. The design of these systems should be based on scaling criteria which will provide the most effective, flexible modules, such that potential wide-range variability in crew sizes and duration for future missions will have minimum impact on the design of appropriate life support system(s).

APPENDIX C
BIOLOGICAL SCIENCES

BIOLOGICAL SCIENCES

The Program in Space Biology

Introduction

In spite of its evocative name, this program is concerned with fundamental aspects of conventional terrestrial biology. The aspects of interest, however, are related to the Earth's environment, and this program is intended to provide answers to refractory problems by carrying out experiments which were impossible until very recently: experiments beyond the Earth's environment.

All life on Earth has evolved under the influences of the sun's electromagnetic radiation and the Earth's gravitational and magnetic fields. While we can determine the biological effects of the absence or presence of magnetic fields and the quantity and quality of electromagnetic radiation, ground-based biological studies with altered gravitational fields are limited to increases in the field above those existing on Earth. We cannot precisely simulate extended weightlessness, although in some organisms we can attempt to "compensate" for it.

The space "environment" is unique in being free of gravitational influence, free of tidal forces, and free of the Earth's magnetic field. Observations and analyses of plants and animals on Earth have shown that these forces have played significant but varying roles in the evolution of life, most of which are still poorly understood. The lack of knowledge regarding the role of gravity is greatest, and the space biology effort is primarily oriented to the study of the effects of gravity on biological systems.

Within the Agency, the findings of this program can have substantial significance. Man's long-duration tenancy of space for Earth's observation, exploration, colonization, or even for more applied tasks such as fabrication of space power stations, will probably require utilization of regenerative life support systems. Basic knowledge of the response of plants and animals to reduced gravity is prerequisite to their use for this purpose. To date, we lack knowledge of the ability of organisms to complete life cycles without the influence of gravity and, hence, are unable to adequately predict the function and reliability of Earth organisms for space bioregeneration. Will gravity compensation or induced gravity be required?

The significance of this program, in a broader sense, can be far reaching. Improvements in the understanding of developmental biology can result from space-biological studies of embryo development and, if achieved, will be of profound fundamental importance. At a more applied level, it is not difficult to envision a program to improve and select plants based on the ability to control lignification, which is known to be cued by the gravity stimulus, or advances in cell culture and somatic and chromosomal hybridization based on freedom from the forces of gravity.

The Present Status of Space Biology

Two questions are dominant:

1. What role does gravity play during the growth, development, function, and evolution of organisms?

2. What role have variations in gravitational and magnetic fields played in the evolution of biorhythms?

A summary of present knowledge regarding the answers to these questions can be distressingly succinct. Although biological responses to gravity are obvious in many instances, current knowledge of the biological effects of gravity is scant and little is known of mechanisms. Answers to the second question must, to a significant degree, follow answers to the first.

Funding in the area of gravitational biology derives almost entirely from this program in NASA. The National Science Foundation (NSF) supports plant hormone research which has applications to gravitational biology, but contributes little to our understanding of gravity perception or to our understanding of the effects of reduced gravity. The USSR has a well-established, and apparently well-supported, program in gravitational biology; their progress has been significant in recent years as our level of effort has been continually reduced.

Within NASA, the technical operating plan for Space Biology includes the following types of investigations:

1. Ground-based studies antecedent to and contributing to subsequent space flight activities:
   a. Research on gravity receptors and geomorphism at both the cellular and organismal level.
   b. Clinostat and centrifuge experiments to identify and predict biological responses to lowered gravity.
   c. Preparation for inflight testing of mechanisms responsible for biorhythms.

2. Investigations requiring spacecraft:
   a. Studies in animals of physiological mechanisms influenced by gravity.
   b. Studies on the mechanisms of geotropic responses in plants and animals.
   c. Studies on the role of gravity in basic morphogenic and cellular processes in embryonic systems.
   d. Tests of hypotheses on control mechanisms of circadian periodicities.

The investigators active in this field come from a variety of backgrounds. In-house staffing is inadequate, and only a few outside investigators have been able to dedicate themselves to gravitational biology at any given time. Recently (within the past two years), a group of new investigators has been brought into the Space Biology research area. This new group includes a few young investigators, several excellent mid-career scientists, and several noted senior biologists. While few of these individuals are experienced in gravitational biology, they bring much needed new ideas and approaches to the field.

Most of the research on gravitational biology has, of necessity, been ground-based, but opportunities for space flight experimentation have been presented by Biosatellite, Apollo, Skylab, and a few other space programs. Unfortunately, with a few notable exceptions, space biological experiments flown, to date, have usually lacked one or more of the following: 1) clearly stated objectives, 2) adequate provision of space, weight, power, or environmental control, 3) high priority and adequate financial support, or 4) truly satisfactory controls allowing close comparisons and detailed interpretations. As a consequence, few definitive U.S. space biological experiments have been flown to date. This is in contrast to the highly successful space biology program in the USSR. Skylab was in manned orbit for 84 days, yet the U.S. has still to grow a plant in space!

Adequacy of the Current NASA Program

The current Space Biology program is well conceived and documented, and is directed by competent scientists; however, some of the investigations supported, both in-house and extramural, are still of marginal quality. While the intended scope of the program is excellent, accomplishments are minimal due to inadequate support. This lack of support may be influenced by the amount of "bad" biology that was done in the past in the name of space biology. It may also be due to the perceived lack of progress in the field by NASA management, which has given little evidence that it appreciates the complexity of biological processes or the difficulty of or requirements for effective space biology experimentation. The inadequate level of support is undoubtedly also due, at least in part, to lack of proper advocacy.

The Future

The advent of Spacelab, dedicated to research in biology, should add significant impetus to research in space biology by providing the facilities and support necessary for definitive biological experimentation. Gravity's input as an environmental influence on the initial development of the developing embryo has been neither obvious nor amenable to successful experimental investigation on Earth. To address this question successfully, it is necessary not only to achieve the first cell divisions of a fertilized egg in space, but also to insure that the egg has no prior "memory" of contact with gravity (except insofar as may be inherent in the genetic heritage of the organism), hence the specific need for multigenerational studies in zero gravity.

It is important for biologists to ascertain whether embryogenesis and subsequent development, which has evolved in a gravity-oriented environment, can proceed normally in the weightless state. The phase of development in which single cells give rise to multi-cellular embryos with morphologically recognizable polarity should be critically examined. The crucial objective of such an experiment should not be merely to test the ability of an egg to form in an embryo sac and to respond to a fertilization stimulus, but to learn whether all the classical phases of embryological development can follow.

As organisms develop in this process, their cells become morphologically and functionally different from one another even though they contain identical genetic information. The mechanism of this cell differentiation is one of the most provocative problems of modern biology, and it is not known whether gravity plays a determinative role by affecting the relative positions of the cells or by affecting the constituents within the cells.

It is important to learn, as the embryo matures in zero gravity, whether the embryo has the characteristic polarity it exhibits on Earth, such as the shoot and root in a seed; and whether growth and development proceed normally, especially in terms of the continued growth and morphogenesis of the highly asymmetric growing regions, which in turn gives rise to all the tissues and organs of the higher plant or animal body.

The truly significant advantage of the dedicated Spacelab will be the presence of trained scientists whose primary mission is scientific experimentation. Unmanned biology experiments in space, to date, have been largely unrewarding scientifically, often because of compromise based on other mission constraints. Mission durations have also been too short to permit the most important questions to be asked. The dedicated Spacelab, and perhaps the anticipated Shuttle/Salyut program, will allow the U.S. to perform life cycle studies in space for the first time. Every effort must be exerted to prevent compromise of these opportunities to perform definitive experiments in gravitational biology.

Recommendations

Gravitational Biology is an area of scientific investigation unique to NASA. Orbiting laboratories which permit periodic examination and manipulation of plants and animals through their life cycles at low gravitational force are requisite for the study of the role of this important variable, gravity, on the physiology, function, and evolution of Earth organisms. Orbital flights at low g (10^{-3} to 10^{-4}) of long duration (30 days and longer) are necessary for fundamental mechanistic studies in gravitational biology. Research in gravitational biology should have priority over research on other variables of the space environment. Experiments selected for flight should be well founded in theory, thoroughly calibrated for quantitative interpretation, and designed to answer important questions on the role of gravity in growth and development. The current program in Space Biology should be critically reviewed for quality, and supported at a level to insure sustained progress.

Environmental Effects

Concern for the environmental effects of Agency operations must have a critical role in NASA planning, ground support, and flight operations. The Agency is required to comply with the national policy for the environment as established by the National Environmental Policy Act of 1969, as amended, and subsequent legislation related to particular features of the environment. In addition, NASA has an implied responsibility to assure that consequences of its operations do not produce effects which impact world-wide environmental systems. Thus, NASA not only has the direct responsibility for planning and conducting its operations in a manner such as to prevent undue damage to the environment but, in addition, must bear the added responsibilities for analyzing and identifying more precisely the undesirable contributions to the environment resulting from its operations, the modification of environmental factors produced by these perturbations, the immediate and long-term responses of animal and plant life and the mechanisms by which these responses are manifested, and the ultimate total impact on the biosphere.

The Status of This Program

In-house and extramural research in this area currently sponsored by NASA is minimal and designed to provide information for the development of an adequate environmental impact statement for Space Shuttle operations. Included are contract-supported efforts to establish a baseline inventory of biota in the immediate KSC area. This inventory must be completed prior to the development of a monitoring system allowing detection of Shuttle launch effects in the local environment. The environmental baseline information under development consists of a variety of data gathering activities concerning the existing flora and fauna of the area and their interactions, existing water and air pollution bases, identification of rare and endangered animal species, and research on the response of selected (including KSC) plant species to simulated solid rocket motor exhaust mixtures and exhaust components from solid rocket fuels.

Numerous additional contract and in-house research efforts are designed to produce information on the biological responses to be expected should Shuttle exhaust products perturb the stratospheric ozone layer. The specific laboratory, field, and theoretical studies underway are germane to the effects of small increases in biologically damaging UV-B on: (1) incidence of human skin cancer, (2) agricultural productivity, and (3) the stabilizing influence of natural terrestrial and aquatic ecosystems.

Adequacy of Current NASA Effort

While the KSC environmental work is supported by the Space Shuttle program, the work regarding the effects of UV radiation is being supported within the Life Sciences program. Funding levels for the latter program are on the following page.

	FY '77	FY '78	(Requested) FY '79
Extramural	399*	394	529
NASA In-House	40	35	33
Space Shuttle Program Support of the KSC Environmental Studies Effort:	319.4	330.0	330.0

*All numbers are in thousands of dollars.

Most of the ecological/environmental effects research is contract-supported at academic institutions or national laboratories, but about one-fifth of the UV-B studies and the microwave review are in-house undertakings at NASA laboratories. Most of the project leaders in the UV-B studies are middle-aged, with only a few younger or more senior scientists involved. The baseline studies effort at KSC involves more youthful investigators.

Future Projections

It is understood that the baseline ecological studies supported at KSC by the Shuttle program are likely to be phased out, perhaps in favor of a monitoring system, after FY 1979. While adequate progress should have been made by that time to terminate certain inventory aspects of the program, other features of the research and new directions should receive continuing exploration. Understanding of the KSC area environment and its physical and biological interactions should be somewhat improved, but will still be little more than superficial by the end of the present effort. Development of a complete monitoring program should permit identification of changes in the biota, but, on the basis of present knowledge, will not necessarily provide a definitive explanation of why or how the changes occurred or of the subsequent wider-scale impacts such as the impact on marine populations whose food sources utilize the KSC area during a portion of their life cycle. Knowledge from the "acid rain" experiments, and those directed to analyses of the effects on plants and the soil environment of other rocket exhaust components, will likely be far from complete by FY 1980 and the likelihood, by that time, of substantial insight into the physiological mechanisms whereby such impacts are manifested is rather remote. Thus, these experiments should be continued and expanded following FY 1979.

The future of the research regarding the biological effects of ultraviolet radiation is not clear, and should be considered carefully. Within Federal scientific agencies, responsibility for evaluation of this problem has generally been given to the Environmental Protection Agency. If it has been decided that this is "not NASA's problem," then the only rationale for continuing this work can be that it is necessary for evaluation of the environmental impacts of NASA operations. If this is the case, we commend the program highly, at the same time asking that the particular operation in question be identified (as has been the case in the KSC environmental studies). Is it to be suggested that the Shuttle, which merely "passes through" the altitude range of interest in this case, poses a significant threat to stratospheric ozone, in the near term at least?

Summary and Recommendations

The Agency can play at least two roles in environmental research. On the one hand, it must carefully evaluate the environmental impacts of its own operations, and must act on these evaluations in an exemplary way. On the other hand, due to its technical and operational capabilities, it can carry out a wide range of extremely useful investigations of the global environment. We recommend that:

1. Studies in the first category be fully supported, both with regard to funds *and personnel*, by the operational program whose environmental impact is being evaluated. At the same time, centralization of these activities in a single office, probably within the Life Sciences, seems to be definitely to the benefit of the Agency.

2. The Agency carefully study the role which it can play in environmental studies, and the responsibilities of the Life Sciences Directorate in such programs be carefully considered and clearly defined. If there is to be any significant Life Sciences involvement, additional, specialized personnel will be required.

The Program in Planetary Biology

Introduction

There is, to put it mildly, widespread and substantial interest in learning about the origin and evolution of life and about the distribution of life in the cosmos. Paleontological studies using rocks and fossils from all over the Earth have provided a great deal of evidence regarding evolution over billions of years. However, everything learned to date, both in those studies and in relevant biochemical and astronautical investigations, indicates clearly that further progress on the largest and most fundamental aspects of the origin, evolution, and distribution of life will require access to even more distant regions of time and space. The exploration of these regions is of central importance in NASA's activities. The Agency is, thus, in a position to make unique and powerful contributions, and has responded to this challenging opportunity by developing a program in "planetary biology."

The creation of a program does not insure its optimal development, however. The Agency has a critical responsibility in this regard, and should recognize a great deal of self interest. Failure to act in the best scientific traditions – failure to identify correctly and pursue actively the truly central issues – would abandon planetary biology to the authors of low grade science fiction. The serious scientific and general public would lose interest in the field, and erosion of interest in space science would follow. Alternatively, the strong public and scientific interest associated with this program can serve as a significant motivating factor for all of space science.

The Scientific Questions and the Status of their Answers

1. When, and by what course of events, did life originate on Earth?

   a. In what environment (physical and chemical)?

   b. What were the principal chemical processes?

   c. Given organic chemical products, how and when did higher levels of chemical, cellular, and organismal organization arise, and what was the relationship between this biological evolution and the evolution of the early environment?

   d. How accurately can these processes be reconstructed from available geochemical and paleontological evidence?

   e. Did life originate only once, or many times, on the primitive Earth?

2. What are the relationships between early pre-biological terrestrial processes and those occurring elsewhere?

   a. How can the evolution of the early terrestrial environment be placed in a planetological context?

   b. What are the relationships between interstellar molecules, related cosmic phenomena, and the origin of life?

   c. Is there any evidence of prebiotic processes and/or of life elsewhere?

3. Can fundamental constraints be placed upon biological phenomena?

   a. Are there molecular systems which are alternative to our protein/nucleic biochemistry?

   b. By what processes can life be distributed in the cosmos?

   c. Given a particular "cosmos environment" (galaxy, star, planet), can the probability that life will arise be estimated and the course of its evolution predicted?

With regard to questions in the first group, we can expect that better knowledge of the conditions elsewhere in the solar system, together with application of the developing principles of comparative planetology, will eventually lead to a substantially more complete understanding of the conditions which must have prevailed in the earliest stages of the Earth's history. Even now, the very earliest geological records are being explored with enormously increased interest and success. The time at which life must have arisen and the timing of some major evolutionary events are becoming increasingly better defined. At the same time, information on the environment, particularly with regard to biologically-related parameters such as the oxygen level, is becoming well developed. The rapidly progressing field of molecular biology contributes much, and could contribute much more, to understanding of the earliest stages of biological evolution. It has been recognized since the first Miller-Urey experiment that abiotic synthesis of organic molecules is a virtual inevitability, and it should become possible to provide a more detailed account of prebiotic chemical processes as knowledge of conditions in the primitive Earth improves.

The second category of questions is characterized by a substantial extraterrestrial focus or component. Highly significant findings have recently advanced the status of this area, indicating, for example, that the amino acids in carbonaceous chondrites are definitely extraterrestrial, and suggesting that carbonaceous chondritic material is widely distributed and relatively abundant in the solar system. The comparative evolution of the lithospheres and atmospheres of the planets is being vigorously studied. The catalog of interstellar organic molecules continues to expand, and knowledge of their distribution improves constantly, reforming our views of the potential impacts of "cosmochemistry" on "prebiotic chemistry."

The first two questions in the third category have been approached as occasional "targets of opportunity," a pattern which will probably continue for some time. The third question, however, represents a view of the search for extraterrestrial intelligence, a quite active field. Well-organized arguments have been constructed suggesting that intelligent life should be expected to have arisen elsewhere in the universe. The question presented here asks, in essence, "Where should we look?" and can be expected to receive significant attention in the near future.

Ongoing Efforts

Lines of Inquiry. Consideration of the questions and research progress noted in the preceding section shows that, though termed "biological," this area concerns itself to a very significant extent with geology, chemistry, physics, and astronomy.

In particular, micropaleontological and organic geochemical techniques are being employed in studies of the earliest terrestrial sediments (the Pre-Cambrian era). The immediate goals of these efforts are the explication of the origins of the organic matter found in these sediments, the coherent interpretation of the microfossil record (including the development of techniques for the secure recognition of microfossils), and the integration of these two lines of evidence. Because it seems clear that the interpretation of the Pre-Cambrian record will be especially difficult, though necessary for this work, studies of more recent sediments (including deep ocean cores) are being pursued with a particular eye to elucidation of the processes affecting the preservation or modification of molecules and structures of paleobiological significance.

It is widely agreed that studies of carbonaceous chondrites offer some of the best hopes of eventually providing information on conditions and processes during the formation of the solar system and, thus, giving the earliest possible views of Earth's history. Unfortunately, there has been a relaxation of effort devoted to organic chemical studies of carbonaceous chondrites. The reasons for this relaxation can be speculated upon, and are of interest. First, the attention of many investigators prominent in this field was diverted by the arrival of the lunar samples. Second, the development of lunar and meteoritic research tended strongly to indicate the value of *integrated* investigations in which many lines of evidence relating to a single sample were brought together in order to allow far more advanced interpretation. This contrasts strongly with pure organic analytical investigations of isolated meteorite samples and, while the highly organized structure of lunar science has continued to generate a well-integrated approach to lunar sample analysis (unfortunately of little interest to planetary biology), there has been no parallel coordination of meteoritical studies (of great interest to planetary biology). Third, the levels of cleanliness, etc., required in meteoritic studies are now recognized to be very high and, therefore, relatively expensive. While funding through the lunar program effectively supported much work on meteorites in the mid-1960's, similar resources are not available now.

Research which is fundamentally chemical concerns itself with aspects of planetary biology relating to the origin of life. Organic chemical studies focus on reactions of plausible importance in prebiotic systems, on the origin of optical activity, and on the isotopic distributions which biological or non-biological reaction pathways create in the organic molecules they synthesize or modify. Studies related to aspects of physical biochemistry are being pursued to investigate potential mechanisms of association and self-organization of organic molecules, and range upward through studies of the origin of the genetic code to studies of possible mechanisms of cell formation. While this line of inquiry is strongly allied with conventional chemical, biochemical, and molecular biological research areas, the context of planetary biology profoundly influences the patterns and goals of the individual investigations.

The approach to some of the questions of planetary biology must be primarily physical, astronomical, or theoretical. Radio and optical astronomical observations of interstellar molecules and, within the solar system, of planetary atmospheres, are offering new information, and the integration of this information with astronomical and paleontological theories is proceeding independently.

Finally, we can observe that there are some classical biological investigations underway in this field. With few, if any, exceptions, these investigations are exploring the adaptation by terrestrial organisms to extreme environments. Originally conceived as relevant to the possibility of an Earth-like Martian biota, these investigations have significance for consideration of biological evolution in the Pre-Cambrian as well as the protection of planetary environments from foreign organisms.

Sources of Funding

The Planetary Biology program supports an appreciable fraction, perhaps 30 to 50 percent, of American academic research in micropaleontology and organic geochemistry of Pre-Cambrian sediments. The remainder of the support in these areas derives largely from the National Science Foundation. The NASA and NSF programs differ in focus, with the former addressing questions in the first category listed in this review and the latter addressing itself largely to chemistry of sediments.

Other programs within NASA contribute substantial funding to research in meteoritics, as well as to the physical and astronomical research programs mentioned briefly above. The National Science Foundation plays a substantial role in these areas as well, but neither it nor the NASA programs in the physical sciences contribute to research programs dealing primarily with the organic constituents of carbonaceous chondrites, a unique and highly important area in which the Planetary Biology program provides virtually all current and much-needed support.

Is the Agency's Approach to this Field Adequate?

With regard to program content: It is possible to suggest areas in which the content of the program could be improved. First, especially in the field of chemical evolution, there is a need for theoretical development. As is typical of many new problem areas, this field has been characterized by an empirical, data-gathering approach. While excellent summarizing reviews have appeared from time to time, and while these reviews and other work have frequently sought to place the field in a broader context, it remains true that studies in chemical evolution are widely perceived as lacking the sound conceptual and theoretical basis that is characteristic of more mature scientific fields. Second, especially in Pre-Cambrian studies and meteoritics, the work supported by the program tends to be of uneven quality, detailed and thorough in the individual investigator's particular speciality, but cursory and sometimes superficial in ancillary areas. The cause of this problem is supremely evident: it is difficult (indeed, perhaps not humanly possible) for a single investigator to be thoroughly knowledgeable regarding all aspects of the natural and physical sciences that impinge on planetary biology. We doubt that these problems are without remedy, and will return to the question of program content in our sections on "Projections" and "Recommendations."

With regard to funding and priorities: If we consider that topics within Planetary Biology can significantly assist in the marshaling of public and scientific support for space exploration, then it would seem that this program should receive very high priority, not only on its own merit, but for the sake of the Agency. Unfortunately, the priority presently assigned does not seem to take this into account, inasmuch as funding has just been cut by more than 12 percent (from \$3.3 to \$2.9 million) at the same time that the Life Sciences budget has increased by 84 percent (from \$22.1 to \$40.6 million), and the total OSS budget has increased by 35 percent (from \$380.3 to \$513.2 million). This reduction has apparently been stimulated by the results of the Viking biology experiment. We regard this as illogical inasmuch as the fundamental questions of planetary biology are very little affected by the Viking results. In fact, it happens that planetary biology is now progressing rapidly toward increasingly interesting areas.

It is, perhaps, the context within which priorities are set that causes the problem in this case. Within the rather narrow primary mission of the Life Sciences Directorate, it is possible to understand the assignment of a relatively low priority in comparison to, for example, vestibular function research. However, within the context of the Office of Space Science, a program of this visibility and interest assumes greater importance, and, we feel, should receive a higher priority.

Summary and Recommendations

It cannot be suggested that the field of planetary biology is well advanced. To a far greater extent than ever before, however, it can be observed that the field has a genuine, independent intellectual existence. The powerful attraction of the principal questions seems finally to be affecting the scientific community at large. As the developments which we have noted in this report continue, it will certainly become increasingly accurate to describe planetary biology as a vital force, helping to drive research in all areas of space science.

In hopes of accelerating progress, we make the following recommendations:

1. Improve funding, not so much because planetary biology has been incorrectly prioritized within Life Sciences, but because this field occupies a special position of public *and* scientific visibility and interest, and acts, for this reason, as a significant driving force in the overall NASA operation. The additional funds should:
   a. be devoted to revitalizing research in selected areas in which the program is already active. The "History of Carbon" effort and the efforts outlined in points 2 and 3 below are good examples.
   b. be used for selective expansion in ways which can place the Planetary Biology program in better contact with important allied fields. Possible examples include (in addition to 3c below) support of spectroscopic investigations of asteroids and outer-solar system satellites, laboratory determinations of the microwave absorption frequencies of potential interstellar molecules, and considerations of the paleo-climatology and paleo-environments of Mars and other planets.
2. Attempt to stimulate greater theoretical developments in the field of chemical evolution, striving, in particular, to establish firmly-based paradigms which can channel research in optimally productive lines of inquiry. As potentially effective means for accomplishing this stimulation:
   a. Provide for better stimulation and communication within the area by scheduling conferences, either independently or in connection with AGU, bringing together the diverse range of investigators in this field.
   b. Try to fund two or three solid new projects aimed specifically at theoretical developments (requires some restoration of funds).

3. In order to revitalize research in meteoritics, establish a program for carbonaceous chondrite studies modeled on the lunar sample analysis program. This development should include:
   a. Significant new funding.
   b. Selective disbursement of samples, with the Agency or its contractor acting in a curatorial role, accumulating a large collection of carefully characterized and subdivided samples.
   c. Carefully planned strategies of integrated investigations ranging from mineralogic and petrologic studies through organic analyses.

   Planning for this program should begin with formation of a board of scientists involving leaders in all aspects of carbonaceous chondrite research.

Clearly, some of the improvements sought through the above recommendations will evolve naturally as the science of planetary biology matures. As the leading supporter of such studies at the present time, however, NASA is in a unique position to act effectively, and vigorously, to speed their attainment.

The Program in Planetary Protection

Introduction

The objective of the Planetary Protection (PP) program is to protect the planets, including Earth, against contamination by alien life. PP has the following logical elements:

- contamination assessment
- decontamination procedures
- containment technology
- consideration of planetary environments
- planetary protection (quarantine) policy
- evaluation and mission planning.

Consideration of these questions is essential to both exploration of planets and possible return of extraterrestrial samples to Earth. The purpose of the PP program is to provide support to missions, and not to answer basic scientific questions unless the answers are vital to missions.

Until recently, this program has dealt with the problems of stringent quarantine, particularly for Mars; namely, probability of growth, quarantine protocols, and decontamination procedures. Now, the emphasis has shifted to the outer planets and to return of samples to Earth. This shift in emphasis has led to an adjustment in scale, scope, and balance of the Planetary Protection program. The research and development in support of strict quarantine has been reduced, while that in support of sample return and outer planets has been increased.

The current operating plan has eight sub-programs:

- PP guidelines for outer planets
- definition of PP requirements for Mars
- development of PP requirements and technologies for sample return
- advanced PP in support of future missions
- microbiology of spacecraft
- evaluation and monitoring of flight missions
- information collection, retrieval, and dissemination
- advisory groups

Recommendations

1. More emphasis should be placed on support of future sample return missions. Containment assessment, containment technology, and decontamination all require considerable research and lengthy development, perhaps a decade. Inadequate R&D in these areas will preclude the planning of sample-return missions.

2. Interactions with the Planetary Biology program and with the Office of Planetary Programs should be intensified in order to be sure that planetary environments are characterized as well as possible from a biological point of view.

3. Further work on strict planetary quarantine is not warranted by future mission plans and should be de-emphasized.

4. The present level of funding in the program should be maintained as the changes recommended above are carried out.

Biological Implications of Remote Sensing

Introduction

In 1975, NASA launched Landsat II, and the population of the world reached a mind-boggling four billion, enough people to form a column marching 100 abreast and a meter apart around the globe at the equator. Strange as it may seem, these two events are not unrelated. The world will need all of its present science and engineering, plus a good bit more, if it is to continue to feed that marching column which widens by three marchers every year. Remote sensing can surely help, and thus has deep biological implications.

The Need for Information

As the number of people increases, the complexity of society increases in a cascading fashion. Increasing amounts of information are required for survival.

That marching column must have food. As one of the biggest breadbaskets in the world, the United States is expected to come through with enough food for every corner of the globe that runs out – the Sahel in Africa during the great drought, India in the bad monsoon years, Egypt despite the Aswan Dam, Russia in desiccated 1972 (and apparently even in 1978, to some extent). Had we known the status of Russian wheat in 1971 and 1972, we would not have been caught as short as we were then. If the nation is to meet this food challenge, we must know the status of food crops throughout the world. We need to know when droughts begin, how fast they worsen, and whether the crops are being seriously damaged by bugs and blights.

NASA has a vast and highly useful background in acquiring and processing information. The Nimbus and Landsat spacecraft, for example, collect and transmit much of the data we need. Landsat was designed, in part, to study the amount and distribution of food crops of the world at any given time. In 18 days, it can photograph every wheat, rice, and corn field in the world, and be back to photograph the first one a second time to see if it has grown, whether it has been harvested, and whether stress factors, such as drought, have adversely affected it.

Information That Remote Sensing Can Provide

Remote sensing furnishes an astonishing amount of environmental information:

a. The acreage of major crops.

b. The condition of the crops.

c. The amount of snow in the mountains for irrigation next season.

d. The status of water reservoirs and rivers.

e. The distribution of soils and land use patterns.

f. The extent of encroachment by cities on farm land.

g. The moisture level in the soils.

h. The distribution of forest types, and of timber volumes.

i. The usage of range land.

The present developments in Landsat technology provide for spectral channels and resolution of one-acre fields. Both false-color "photographs" and computer-drawn maps are available for interpretation *via* correlation with ground-truth information.

Applications have been concerned with agricultural assessments and with water surveys. The "Large Area Crop Inventory Experiment," LACIE, has been carried out in cooperation with the Department of Agriculture, the Department of Commerce, and the National Oceanographic and Atmospheric Administration. After preliminary stages in which inventories of the U.S. wheat crop have been compiled and compared with ground truth, the inventory procedure is being applied with great success to the world wheat crop.

Further applications have considered patterns of land use. It was revealed, for example, that urban development around Phoenix, in Mariposa County, Arizona, has significantly affected the acreage available for production of winter vegetables, thus presumably exacerbating market shortages and providing an additional factor responsible for rising food costs. The remarkable value of modern agricultural techniques, even in the most extreme environments and conditions, has been demonstrated by Landsat findings which have shown the benefits of controlled grazing in the African Sahel.

The future of this technology depends, to a significant degree, on the willingness of the users to pay the costs. Substantially improved spacecraft can be deployed if funds are available. The program is being evaluated in a critical and crucial way by the international community of users. A series of highly practical economic and political decisions will determine its future. To increase the chance that the full potential value of this technology is widely appreciated and considered for use, we recommend that:

1. The Agency take the lead in informing new users, e.g., lumber companies, county farm bureaus. An amazing variety of potential beneficiaries exists.

2. In order to provide the continuity required to attract large-scale users, the Agency make every effort to maintain the flow of high-quality data.

3. The Agency seek to coordinate international applications, particularly with "third world nations," *via* AID and the World Bank, and that unrestricted access to all data be allowed.

4. The Agency should seek to improve the available technology, in particular by:

   a. improving machine interpretation of data

   b. providing more spacecraft

   c. combining data with meteorological information

   d. providing information regarding the signatures of "non-American" crops, especially those relied upon for foreign exchange in the third world.

5. The Agency should take appropriate steps to increase real-time data appraisal.

APPENDIX D

PAYLOADS AND APPLICATIONS

PAYLOADS AND APPLICATIONS

Life Sciences Flight Experiments Program

Rationale

The Life Sciences Flight Experiments (LSFE) program establishes the capability through the Space Transportation System (STS) for conducting life sciences research and development in space, and for exploiting the uniqueness of the space environment to study the effects of weightlessness on a variety of biological specimens, including man. For the first time, the capability for scientists to fly in space without having to be astronauts is provided on a frequent basis. The Spacelab provides the capability to fly large numbers of life sciences experiments, to retrieve and reuse experimental equipment, and to undertake sequentially related studies. Opportunities for the life sciences community to participate in the STS flight program are extensive.

The LSFE program supports development of dedicated Spacelab payloads, minilabs, and carry-on payloads. The objectives of the program are: first, to organize and develop the resources and capabilities (i.e., equipment, facilities, personnel, procedures, and planning) to support the flight project, and second, to apply effectively the resources and capabilities to accomplish the payload flight projects.

The configuration and equipment that make up each life sciences laboratory will vary from mission to mission, depending on the complement of experiments to be performed. Equipment included in the flight laboratory may be divided into two basic categories. Equipment that is typically required to perform one experiment only is identified as experiment-unique equipment. Equipment that is commonly used for life sciences experiments and can generally support several experiments on a mission or can be flown on several missions is referred to as life sciences laboratory equipment (LSLE). This latter activity was formerly known as CORE (Common Operating Research Equipment).

Status

The science community has shown a strong interest in the LSFE program. Several thousand responses have been received to an "Invitation to Participate in Planning the NASA Life Sciences Program in Space." Responses were received from all segments of the life sciences community, representing more than 500 institutions and private organizations. Announcements of Opportunity for the Spacelab 1 and 2 missions and for the Space Shuttle orbital flight test have also had a strong life sciences response. For example, 38 percent of the responses to the Spacelab 1 Announcement of Opportunity were for life sciences experiments. Some 360 experiment proposals were received from the life sciences community in response to the most recent Announcement of Opportunity (for the first dedicated Life Sciences Spacelab).

With regard to LSLE (laboratory equipment), as originally conceived, both animal and plant facilities would be designed, developed, and readied for use in the first Spacelab. Due to restricted funding, however, only the animal facility is proceeding on schedule. A limited plant experimental facility is being readied to support a scientific experiment, and it is hoped that the design will be sufficiently flexible to support other plant investigations. Preliminary design review indicates that this may be so, at least to a limited extent. As of May 1978, the overall LSLE program appeared to be still in the preliminary analysis and design phase.

Adequacy of Current NASA Funding

The LSFE program funding includes Principal Investigator contracts, experiment-specific equipment development, facility operations, ground-support equipment, science operation planning and support, data analysis, and experiment integration planning and implementation. It is apparently too early to tell whether LSFE funding is adequate.

In the LSLE program, there appear to be limitations in the funding of Spacelab equipment design such that the facility for plant experimentation is behind schedule and may be inadequate.

Summary and Recommendations

The dedicated Spacelab represents the first U.S. space facility capable of supporting definitive, reproducible biological experimentation designed to answer fundamental questions on the role of gravity on the evolution of life on Earth, the mechanisms of the gravity stimulus and receptors, and the requirements for the gravity stimulus for normal growth and morphogenesis of plants and animals. The Spacelab also represents the first U.S. opportunity to grow plants and animals in a gravity-free environment for the purpose of conducting life cycle studies to elucidate such observed pathophysiologic phenomena as space motion sickness and bone demineralization. Hence, it is critical that facilities to support subject experimentation be developed on a timely basis for *both* animals and plants. The support Life Sciences programs for this facility, Life Sciences Laboratory Equipment (LSLE) and Life Sciences Flight Experiments (LSFE), therefore, should receive firm and continuing funding during their planned duration.

Vestibular Function Research

Rationale

NASA has two reasons for support of Vestibular Function Research (VFR) as a flight experiment:

- A fundamental biological question of gravity sensing/adaptation
- A major problem of space motion sickness.

Status

Approximately 50 percent of the astronauts have had space motion sickness during the first two to four days at zero gravity, and the astronauts generally show transitory impaired balance immediately after return to Earth's gravity. Space motion sickness has no effective prophylaxis or therapy.

The gravity receptor of vertebrates is the otolith, a portion of the inner ear. The response of the frog otolith to stimuli is markedly altered during the first four to five days at zero gravity, closely paralleling the period of susceptibility of astronauts to space sickness. The VFR flight experiment is related to NASA-supported laboratory experiments on motion sickness in human subjects and laboratory animals (e.g., cats).

Critical Questions

The critical questions are as follows:

- How is the transducer (otolith stones, otolith membrane, and cell hairs) physically altered by zero gravity?
- What is the mechanism of adaptation? What are the roles, respectively, of change in the receptor and of efferent control by the central nervous system?

Answers to these questions will guide efforts at prophylaxis and therapy of space motion sickness.

Adequacy of Present NASA Programs

The current plan is to fly a VFR experiment on Spacelab 3 in 1981. The hardware subsystems consist of life support, centrifuge/tilt mechanism, specimen transport, and data. Construction of a prototype and engineering evaluation is scheduled.

Summary and Recommendations

The VFR flight experiment addresses a major question of the mechanism by which vertebrates sense and adapt to gravity. It rests on a reasonably good scientific basis, but the cost is great. The results may guide future studies of mammalian vestibular function and thereby may contribute ultimately to solving the problem of space motion sickness.

Kosmos

Rationale

The Kosmos program of the USSR permits international participation in space. Participation by U.S. scientists is supported and administered by NASA, and serves the following purposes:

- Strengthening international scientific relations between the U.S. and USSR, as well as other participating countries

- Establishing interaction between scientists in the U.S. and USSR
- Training of U.S. scientists in space flight experimentation during a period when the U.S. has no space flight opportunities, and doing so at low cost.

Status

The Kosmos program has permitted biological experimentation in hypogravity of intermediate duration with an onboard centrifuge for 1 g controls. U.S. scientists have participated in two flights:

- Kosmos-782 (November 1975) with 12 U.S. experiments, 19.5 days duration
- Kosmos-936 (August 1977) with seven U.S. experiments, 18.5 days duration.

Important results were obtained on, among others, morphogenesis of plants (carrot development), production of erythrocytes, bone growth and decalcification, and characterization of the radiation environment.

Complex logistics and requirements of international cooperation have compromised performance of some of the experiments and confused interpretation of some data. The central problem has been lack of control by the investigators of the conditions of their studies, both for experimental and control animals and material.

Clinical Uses of Space and Clinical Application of Space Technology

The overall objective of this program is to examine the zero gravity environment as a useful tool for clinical investigation and to review the results of clinical studies in space for procedures of possible usefulness to therapy of disease. Any disease process is the result of a complex interaction between host, agent, and environment. Since so many diseases are difficult to understand and to treat, all avenues should be explored. On that basis, it is reasonable to consider the potential value of the effect of the space environment on disease processes.

The three principal characteristics of space flight thus far evident are weightlessness, relative physical inactivity, and confinement-isolation. To date, our manned space flights have provided a great deal of information about the physiological responses to weightlessness (the zero gravity environment) of many body systems. These responses (in the musculoskeletal system, fluids and electrolytes, cardiovascular system, and others) are described in Appendix A.

The ongoing effort in this program on the Clinical Uses of Space is directed toward the following:

1. Medical research uses of space: Examination of basic mechanisms of disease with the aid of this unique environment, using systems from cellular to total organisms – man or animal.

2. Clinical uses of space: Investigation of the unique features of the space environment for potential use in the treatment of disease, following the example of the manner in which hyperbaric pressure is being used and evaluated in tetanus and multiple sclerosis.

3. Development of unique clinical equipment for use in space. Although the primary objective in this segment is to design and produce equipment for use in biomedical studies in space, there is a strong secondary objective of application of such apparatus for use in clinical medicine on Earth, which is separately identified in the program called "Biomedical Technology Applications."

The ongoing effort includes a number of equipment development activities and applications of space techniques to ground-based medicine: development of microminiaturized hybrid circuits for use in a variety of medical diagnostic and physiological function tests at very light weight and low power, such as obtaining blood pressure, ECG, respiration and temperature; development of a cost-effective telemedicine network between hospitals of visual, graphic and digitalized material; microwave links to transmit bedrest data between medical research facilities conducting such studies; and a medical image analysis facility at the Jet Propulsion Laboratory for application of computer X-ray analysis techniques to research and diagnostic procedures in the cardiovascular, bone, and muscle systems. The successful remote telemedicine diagnostic and consultative system development (STARPAHC), under trial at length on the Papago Indian Reservation in Arizona, has been transferred to the Indian Health Service, PHS, Department of Health, Education, and Welfare.

Two tasks at Ames Research Center are aimed at developing magnetocardiography recording capability and then applying it to clinical use, and possibly to manned space flight. The method is totally noninvasive, requiring no electrode contact. This new technology will be space-adapted if it proves to be a reliable noninvasive technique on the ground.

Only one task is directed at the first two objectives – investigation in space of disease mechanisms and using zero gravity as a treatment for disease. This program, at Johnson Space Center, is aimed at interesting potential medical investigator groups through direct marketing techniques and symposia. Such an effort should generate tasks in these objective areas, if it is properly pursued with a multidisciplinary life sciences team with strong medical input from the NASA side.

The critical question is embodied in the first two objectives: Can the unique characteristics of the space environment contribute, through perceptive investigations, to greater understanding of basic mechanisms of disease and/or to new or improved treatments for disease?

This research area is funded at a moderate level in 1978, and is scheduled for a one-third decrease. The bulk of the funding is for contracts. JSC, ARC, and JPL are the Centers involved, with JPL being funded only for 1978. This effort is specifically pertinent to NASA and is not duplicated by any other Government or civilian agency. Additional funding is in order if the life sciences community's interest can be generated by the proposed activities.

Biomedical Technology Applications

The National Aeronautics and Space Administration has long had a goal to "spin off" to ground-based uses the technology developed to support space flight. The Life Sciences portion of this activity has as its goal the expeditious transfer of appropriate NASA-developed technology to the medical community. In order to achieve this goal, NASA must develop an awareness of the significant medical problems and their technological needs, search the NASA technology base for potential applications to the perceived need, and, finally, assure that the technologic solution will have appropriately wide use, interest, and participation (financial) from industry or other Government agencies.

This activity, with the objective of increasing the payoff of space operations to the nation and its taxpayers, is very important. The program has been difficult, and public relations efforts have created little awareness of its potential. It also requires careful review of proposed problems and solutions, from a life sciences and medical point of view, to protect the effort from exploitation by a user and to have a knowledgeable interface with medical community requestors. Biomedical applications teams were formed in 1966 to facilitate the identification of community medical needs and match them with appropriate NASA technology developments. They are located at the Stanford University, the University of Wisconsin, and the Research Triangle Institute in North Carolina.

The primary program is the responsibility of the Technology Utilization (TU) Division of the Office of Applications. The Life Sciences Directorate serves in a liaison capacity, providing necessary medical guidance to the program. The few additional tasks supported by the Life Sciences supplement the overall effort in areas closely allied to its primary activities. Present tasks in the TU Program range from support of the biomedical teams to a large array of specific applications, such as an implantable intracranial pressure monitor, a hip joint prosthesis allowing bony growth attachment, a magnetic cell-sorter, a low-intensity X-ray image intensifer, etc. There are 41 tasks funded for $2.3 million. Recent news articles have noted the whole body hypothermia suit for National Cancer Institute patients with no mention of original NASA support for body-cooling suit studies.

This is, indeed, a NASA Life Sciences responsibility, and efforts should be coordinated with possible Earth resources medical applications and with the JSC stimulatory efforts on clinical uses of space. Any increased effectiveness of this program would benefit NASA, Life Sciences, and the nation.