# Life Sciences in Space

Report of the Study
to Review NASA Life Sciences Programs
Convened by the
Space Science Board
National Academy of Sciences
National Research Council

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NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1970

Available from

SPACE SCIENCE BOARD
2101 Constitution Avenue
Washington, D.C.  20418

# Space Science Board

# Study to Review NASA Life Sciences Programs

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# Preface

In August 1969, the National Aeronautics and Space Administration asked the National Academy of Sciences to conduct a review of the life sciences activities within NASA. The request stated in part:

> "At the present time this country is completing what might be termed a first phase in the exploration and utilization of space....Under the circumstances, it is important that the country plan carefully and choose wisely its course in space over the next decades....At this time it is appropriate to review the life sciences efforts within NASA--to take stock of what we have learned from past successes and mistakes, to determine what should be our goals and objectives for the future, and to decide the best and most effective way of achieving those goals and objectives. NASA would be most grateful if the Academy of Sciences would undertake to conduct such a review, and give us the advice and counsel of the Academy on how our space program can contribute most effectively to the life sciences, and how the life sciences portion of the program should be organized and conducted to take full advantage of the opportunities that lie before us."

In response to this request, a Study to Review NASA Life Sciences Programs was organized under the chairmanship of H. Bentley Glass, Academic Vice President of the State University of New York at Stony Brook. Following an organizing and briefing session in May 1970, the Committee made site visits to the major NASA Centers involved in life sciences activities and, in July, held two weeks of sessions at Woods Hole, Massachusetts. Nineteen consultants were invited to the Woods Hole sessions to give the Committee the benefit of their experience--as experimenters, advisors, participants in earlier studies, or managers--with NASA life sciences work.

This is the report of the Study. Its findings and recommendations were presented in August 1970 to NASA management, as well as to the Space Science Board's Space Science and Applications Priorities Study then convened to recommend priorities and levels of effort in the next decade for the nation's space science programs.

We are grateful to all those who participated in the Study. Special appreciation is due Dr. Glass for his thoughtful and imaginative chairmanship and for his diligent work in the preparation of the Study's report. The Space Science Board acknowledges with appreciation the support of the National Aeronautics and Space Administration.

Charles H. Townes, *Chairman*
Space Science Board

# Contents

# 1 Summary and Major Recommendations

The successful Apollo landings on the moon mark the attainment of the primary goal of the National Aeronautics and Space Administration for the 1960's and necessitate a reappraisal and reorientation of the objectives for the next decade. The objectives indicated by President Nixon in his statement of March 7, 1970, reduce to three: exploration, scientific knowledge, and practical application. Because the enlargement of human understanding and the increase of scientific knowledge occupy a position of growing importance in the official justification of the support of NASA's programs (see pages 9-10), the need to re-evaluate the NASA programs in the life sciences is clear.

The present Study was convened under the auspices of the Space Science Board in the spring of 1970 to undertake this task. The Committee has visited major laboratories of NASA where life sciences work is being conducted and has conferred with numerous consultants now or previously engaged in the various aspects of life sciences work supported by NASA. It also examined the more recent surveys and critiques of NASA life sciences programs. Among these, *Space Biology*, the report of a study convened by the Space Science Board in Santa Cruz, California, in the summer of 1969, and the report (1969) of the Space Science and Technology Panel of the President's

Science Advisory Committee, entitled *The Biomedical Foundations of Manned Space Flight*, received particular attention. The present Committee, composed for the most part of biologists not previously engaged in NASA programs and largely unfamiliar with the scope and the details of the life sciences programs supported by NASA, must disclaim any readiness in so short a time to provide a definitive evaluation of the total program in all details.

Nevertheless, in the three months of our preliminary planning and site visits and the more intensive two-weeks' study conducted at Woods Hole, Massachusetts, July 12-25, 1970, we have been able to arrive at a consensus about broad priorities in the life sciences as well as about the effectiveness with which NASA is currently able to pursue its life sciences objectives. The present report will be limited to these matters.

First, our Committee agrees that *exobiology*--the inquiry into the existence of life elsewhere in the universe and the scientific explanation of the origin of life--represents the most important basic question in the life sciences disciplines associated with the space program as well as one of the great scientific questions of our time. In this we concur with the views expressed in the NASA Report for the Space Task Group, 1969 (see page 14 of the present report). We are not optimistic, however, about finding living things elsewhere in the solar system: the moon is quite lifeless, and Mars, which presents the greatest probability for life of any of the planets, has an environment hostile to life as we know it. We believe, nonetheless, that the search for extraterrestrial life is a prime scientific goal, one that must be a part of any program of planetary exploration. Exobiology embraces considerably more than the simple question, "Does life exist elsewhere than on our earth?" The further questions that must be asked, and that must determine experimental strategy in this area, include the following: Has life ever existed, in former ages, upon the celestial body being examined? Are there indications of prebiological chemical evolution that would support or clarify present ideas about the origin of life? How does life develop? What are the environmental conditions that would prevent terrestrial organisms from populating the planet? Can a lifeless moon or planet, by controlled modification of the environment, become a laboratory for the adaptation and evolution of terrestrial life? In pursuing answers to these question, NASA can also make very important contributions by support of fundamental studies here on earth. Nevertheless, earth-based studies must remain preliminary.

They can only provide useful guides to the definitive explorations to be made in space itself.

Second, we agree that if *manned spaceflight* is to continue and be further developed, then there must be a much stronger and more broadly based program of research in the physiology and psychology of man in space, over and above the aspects of biomedicine concerned with the safety and efficiency of the astronaut or space passenger. We regard this consensus of our Committee to be in agreement with and parallel to the President's Science Advisory Committee Space Science and Technology Panel's emphasis upon the need to "qualify man for space." Unless this can be done, all other missions depending upon man in space must fail or be severely handicapped. We agree with that report's view that NASA has not had an adequate scientific program directed toward this goal.

Third, if the space station and space shuttle represent the technological goals of the coming decade, then such facilities should certainly be adapted to include an appropriate program in *space biology*. As citizens and scientists, we cannot avoid uneasiness over the large costs involved relative to the prospective gains in scientific knowledge. We have asked ourselves whether a better understanding of biological rhythms, radiation effects upon man and other organisms, and the biological effects of gravity and weightlessness justifies so great an expenditure of public funds in comparison with other fundamental biological problems and critical needs for federal support of the life sciences. Yet we also realize that Skylab, the space station, and the space shuttle will be programmed or abandoned for reasons other than the expectation of making important biological findings. We therefore reiterate our conviction that if the new space facilities are to be developed, they should provide for well-chosen and well-designed biological experiments.

Fourth, we emphasize the excellent opportunity for NASA to promote *international cooperation* within the life sciences. Much has already been done to encourage international participation in the planning and execution of certain kinds of experiments conducted in space. This is commendable. Nevertheless, more can be done in biological and biomedical experimentation, and, in view of the extensive Soviet manned and unmanned flights, cooperation with Soviet scientists is of significant mutual interest and should be earnestly sought.

Fifth, even a preliminary survey of the *organization of the life sciences programs* within NASA has disclosed grave defects, resulting from overlapping authority, insufficient internal communication, a multiplicity of advisory groups, each with a very limited purview, inadequate programmatic involvement on the part of the life sciences community, and lack of any strong representation of the interests of the life sciences at high administrative levels. We are convinced that before any reordering of other priorities within the life sciences, there must be a thoroughgoing reorganization of NASA's administration of its life sciences programs. The present system exists for historical reasons which were presumably compelling at the time but which no longer obtain. Repeated recommendations for a reform of the administrative structure have remained unheeded. Without reorganization along such lines as our Committee and others have recommended, it is folly to expect any major improvement in implementation of goals and in the development of the life sciences within NASA. If the programmatic objectives stated above are worthwhile, then a better organization with a strong central voice for the life sciences must be sought to achieve them. The matter cannot be postponed without the gravest future damage.

## MAJOR RECOMMENDATIONS

1. We *recommend* the appointment of a Life Sciences Advisory Board at a high administrative level within NASA, to review programs on a continuing basis and to recommend policies and priorities. This Board should have rotating-term appointments of individuals who are not currently staff members, grantees, or contractors of NASA.

2. We *recommend* the creation of a new Office of Space Biology and Medicine (OSBM) headed by an Associate Administrator for the Life Sciences or, alternatively, of a Deputy Associate Administrator for the Life Sciences in the Office of the Associate Administrator, in that order of preference.

3. We *recommend*, in either case of Recommendation 2 above, a functional reorganization of the life sciences programs, along disciplinary lines, into four Units: Exobiology and Planetary Ecology, Space Biology, Human Biology and Aerospace Medicine, and Personnel Health and Evnironmental Medicine. A biotechnology research group to coordinate the life sciences programs with physical science technology should be made an integral part of the life sciences organization.

4. We *recommend* a simplification of the advisory structure and a reduction in the number of advisory committees and panels. Each of the four Units proposed in Recommendation 3 should have a single advisory committee to review plans and projects and to evaluate applications in support of in-house programs. Advisory groups or panels, organized along disciplinary lines, would be named to evaluate proposals for support of outside investigators.

5. We *recommend* the establishment of better criteria for the selection of flight experiments based on a careful review of existing criteria. The proposed Life Sciences Advisory Board should have a major role in the final decisions with respect to these criteria. As a continuing body of experts, it should be able to advise and recommend priorities in programmatic strategy and planning which an *ad hoc* committee such as the present one is unable to do in a few months of study.

6. We *recommend* the establishment of a NASA Life Scientist Program, in which up to 40 appropriately selected life scientists would receive six-year appointments (renewable once), with salary and minimal supporting research funds. Appointees would agree to spend one third of their six-year term (suitably arranged) at one or more of the NASA Centers or field stations. We are unanimous in the belief that no similar expenditure of funds by NASA will do more to generate the increased involvement of the scientific community, and that no other program will so quickly redound to the benefit and improvement of the life sciences programs of NASA.

7. We *recommend* that NASA inform the life sciences community, especially university staffs and students, more generally of its future plans and of opportunities to contribute to the planning of life science objectives. When definite plans and programs are formulated, the life sciences community should be informed well in advance of target dates, and specific research projects should be solicited with greater lead-time than in the past.

8. We *recommend* that an additional vigorous effort be made by NASA to encourage international participation in the planning and conduct of experiments in its life sciences programs and especially to seek active participation by the Soviet Union.

9. We *recommend* that the search for life on other worlds and for deeper understanding of the origin of life (exobiology) remain the prime scientific priority of NASA life sciences, one commensurate in importance (though not necessarily in expenditure or immediacy) with other primary scientific objec-

tives of NASA. This recommendation does not imply endorsement of any specific presently planned experiments (e.g., Viking): our Committee does not feel that it should endorse or criticize such experiments without a much more exhaustive study.

10. We *recommend* that, if manned spaceflight is to continue, then, in order to ensure the safety and efficiency of man in space and to "qualify man for space," a far broader program of space biomedicine and human biology should be undertaken. In particular, programs in space physiology and psychology must be selectively strengthened. The criteria for selection of astronauts and space passengers must be re-evaluated periodically and should envisage a progressive transfer of the tasks of collecting data and conducting experiments from astronauts to persons trained as scientists.

11. We *recommend* that fundamental studies in space biology, and the supporting ground-based experiments in particular, continue to receive support, and that, because funding for and space within spacecraft must inevitably remain limited, only definitive experiments should be given preference for flight. Accordingly, 90 percent or more of the preliminary work necessary for experiments selected for flight, and probably most of the controls, should be ground-based. It is therefore appropriate for NASA, even within the strictest mission orientation, to support extensive ground-based biological research.

# 2 Mandate of the Committee

The Study to Review NASA Life Sciences Programs was convened under the auspices of the Space Science Board, National Academy of Sciences-National Research Council, in the spring of 1970 in response to a request of the National Aeronautics and Space Administration for a comprehensive study of its activities in this field. The Study itself, and its timeliness, were occasioned by the need to shape NASA goals and priorities for the 1970's and by the fact that none of the numerous appraisals of these activities since 1963 had addressed itself to the entire range of the NASA life sciences work. The Committee was requested to review the past record, to reappraise goals and objectives, and to recommend the most effective ways of achieving them. It was asked to examine both how the space program of NASA could most effectively contribute to the advancement of the life sciences and also how the life sciences programs could enable space explorations to progress most satisfactorily. To support these ends, it was asked to develop general guidelines for the organization and conduct of the life sciences activities within NASA.

The Committee was further requested to make recommendations, concerning the NASA life sciences programs, to the Space Science Board's Study on Space Science and Applications Priorities, which would undertake in the summer of 1970 to recommend the scientific priorities and levels of effort to be assigned during the coming decade to NASA programs in lunar exploration, planetary exploration, solar-terrestrial physics, astronomy, the life sciences, and space applications to the terrestrial environmental sciences. In particular, the Priorities Study was asked to develop general criteria for establishing scientific priorities at various levels of funding. The consideration of appropriate criteria for establishing priorities for the life sciences was therefore a further charge to the Life Sciences Review Committee.

# 3 The Role of the Life Sciences in NASA

The general goals and objectives of the National Aeronautics and Space Administration were set by the National Aeronautics and Space Act of July 29, 1958, under Title I of the Act. Those objectives to which the life sciences clearly do or might relate are the following:

"1. the expansion of human knowledge of phenomena in the atmosphere and space;

[2. not applicable];

"3. the development and operation of vehicles capable of carrying...living organisms through space;

"4. the establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;

"5. the preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;

"6. the making available to agencies directly concerned with national defense of discoveries that have military value or significance...;

"7. cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results thereof; and

"8. the most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment."

During the 1960's the top priority in the space program was given to the goal, set by President Kennedy, of placing a man on the moon by 1970. This goal was illustriously achieved, as all the world knows, but at the cost of making every other aspect of the space program secondary to the immediate problems of manned spaceflight.

On March 7, 1970, President Nixon outlined his policy for the development of the space program during the 1970's. Stating that "our approach to space must continue to be bold--but it must be balanced," President Nixon identified three general purposes that should guide the space program: exploration; scientific knowledge; and practical application, including medical insights, new methods of communication, better weather forecasts, new managerial techniques, and new ways to provide energy. He emphasized that the space program was to be continuing and flexible, "a normal and regular part of our national life." As six specific objectives, he set the following: (1) continued exploration of the moon; (2) exploration of the planets and the universe; (3) substantial reduction of the cost of space operations; (4) extension of man's capability to live and work in space; (5) hastening and expanding the practical applications of space technology; and (6) greater international cooperation in space. It is in the context of these general and specific objectives that the particular objectives and priorities of the life sciences programs must be reviewed.

In the view of the present Committee, future support of the U.S. program in space should depend heavily upon its scientific content. Other prime purposes underlie the effort, such as human adventure and national prestige or maintenance of certain defense capabilities. The practical applications may be of great value. Nevertheless, a major justification at both popular and legislative levels must be the expansion of human understanding. We explore in order to see farther and more clearly than ever before, and because we are curious to know the unknown. Without question, human progress is related directly to human power, and that power grows exponentially with knowledge and understanding. Of all such knowledge, that of science, pure and applied, is the most precise and the most susceptible of social application. Whether this justification is valid in the present context hinges on the ability of NASA to formulate, communicate, and accomplish a program to explore and exploit space in a manner compatible with the finest traditions of science.

We are in a period of austerity for the national scientific establishment and of increased concern with social goals. The National Aeronautics and Space Administration will be asked with increasing urgency to justify what it is doing in space and to state what is being learned from a program whose unit experimental cost is up to a thousand times greater than that of earth-bound laboratories. The answers to these questions, whether before Congress or in public debate, must be put in terms of a net gain of knowledge that is of scientific or social significance. That includes the future exploitation of the moon or of Mars for human purposes or the technical achievement of space laboratories or interplanetary manned vehicles.

Any group of life scientists asked to examine the programs of NASA must attempt to answer two fundamental questions: first, can they under any circumstances justify the expenditure of such large sums for the currently announced objectives of space exploration; and, second, can they endorse the life sciences portion of the space program, in view of the immense unit cost of experiments in space and the sharp decrease in federal funding for the life sciences nationally?

Although our response to these two challenging questions is not unanimous, we share certain convictions. The first is that during a period of great social stress and need and extraordinary military expense, it is proper that the NASA budget has been somewhat reduced. It is problematical whether it can be reduced very much more as long as manned spaceflight is an active part of the program, because manned spaceflight accounts for almost two thirds of the total budget. With completion of the moon landing, most of the announced scientific objectives of NASA are in the area of lunar geology, solar-system planetology, astronomy, and solar-terrestrial physics. Few, if any, of these objectives would have been funded by Congress at the present level had they not been linked to NASA's manned space program.

In regard to the life sciences component of the space program, we express some diffidence. To find that life is not confined to the earth but that it exists, even in primitive form, on some other body of the solar system might well exceed in popular interest and scientific significance any other discovery of either physical or biological nature that the space program could afford. The probability for this was slight to begin with and now seems to be remote, because Mars appears almost as inhospitable for life as does our moon. There are, however, other important questions about the origin of life (see page 2) which might receive an answer through further planetary explorations.

Although the budget for the biomedical sciences comprises but a small part of the total NASA budget, this expenditure does not adequately reflect the interest of both scientist and citizen in the life sciences. Moreover, if for whatever reasons manned spaceflight is to continue, the biomedical programs needed to qualify man for spaceflight must continue. In manned spaceflight, *man*, a living organism, is passenger and pilot, and the machine must match the man. To design the machine without knowing the physical and psychological capacity of the man--large or small, male or female, few or many--to function effectively for long periods of time under all the varying conditions imposed upon him in space is to court disaster. A large part of these mission-oriented research programs can be earth-based, but the effects of weightlessness and its interaction with other variables of the spaceflight environment can ultimately be tested fully only in the space environment itself.

The costs of space biology are enormous in relation to conventional laboratory studies. The Biosatellite program, for example, cost about $156 million. Will investigations into basic biological mechanisms conducted in Skylab or the space station, in biological satellites, or, conceivably, on the surface of the moon or Mars, produce scientific knowledge worth the great expense of the experiments? We have grave doubts. Only the definitive, critical experiment or observation ought therefore to be validated for space itself--only the experiment that cannot be duplicated or appropriately simulated on the ground.

It needs to be kept in mind that although NASA support of the life sciences is small in the total budget of the Space Agency, it constitutes a not insignificant fraction of the total federal support given to the life sciences.* The debatable

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*NASA obligations for research in life sciences in fiscal year 1968 were $98,313,000, or 6.4% of the total federal obligations for such research ($1,537,362,000). Source: National Science Foundation, *Federal Funds for Research, Development, and Other Scientific Activities*, Vol. 18 (U.S. Govt. Printing Office, Washington, D.C., 1969).

position in national priorities of the space program in general, and of its biological components in particular, makes it imperative to review, coordinate, and strengthen the life sciences programs of NASA and to centralize administration of the latter so that maximum benefit can accrue from this large expenditure of national resources.

## THE USEFULNESS OF THE LIFE SCIENCES TO NASA

Man himself is an animal species, a vertebrate, a mammal, a primate. He shares with related animal species certain attributes, certain needs, and certain limitations which are the result of millions of years of adaptation to the terrestrial environment. Any manned venture into space therefore requires a biologically and medically characterized environment within the space vehicle which will permit the astronaut to live in reasonable comfort, to function effectively, and to return safely. It follows that every biological finding about the nature and tolerance limits of the human body--respiratory system, cardiovascular system, nervous system, sense organs, digestive system, excretory and glandular organs, muscles, skeleton, skin, and even reproductive system--assists in the design of the support system without which life must falter or fail. The essence of the task is to match the man and the machine, to "qualify man for flight," and to adapt the machine to maximize human safety and efficiency. The scientific study of man, or of surrogate primates, under conditions of limiting tolerance, on earth and in flight, is therefore basic to the mission of manned spaceflight.

But is manned spaceflight essential to the further missions of NASA? Can the exploration of the solar system be pressed forward, the necessary scientific knowledge be obtained, the national prestige be won, the practical applications flow in full measure, from unmanned probes, flybys, or landings? The answer seems clear. Never was the prestige of NASA higher than when man stepped for the first time onto the moon. No automation can be devised at present to replace the scientist-astronaut in the laboratory of the space station. (We concur in the view expressed in the PSAC Report, p. 10, that "...the performance of scientific experiments in space can be expected to develop eventually in a form that will require man to perform demanding tasks vital to mission success.") No robotcomputer system can yet equal man in his ability to recognize at a glance the individual gestalt of a face or a landscape and to draw appropriate conclusions. Man is still needed--though for how long this will be true we do not know--to operate and repair his machines, to perform his experiments, to program his computers, and to draw his final conclusions.

As for other benefits accruing to NASA from its support of the life sciences, it need be said only that the increase of scientific knowledge is a major purpose of NASA. *America's Next Decades in Space: A Report for the Space Task Group* (1969, p. 72) states boldly: "The discovery of extraterrestrial life would likely rank as the greatest scientific discovery of the century." In any case, the search must be pressed. Even if once and again the answer appears to be "No," that very knowledge is itself important to man, who will find himself more than ever an isolated being on a tiny sphere which by a concatenation of miracles has acquired an environment in which life could appear and evolve. How much of that environment is itself the product of the organisms that live on earth? How can its remarkable balance of vital conditions be maintained?

## THE CONTRIBUTIONS OF NASA TO THE LIFE SCIENCES

The life sciences have certain characteristics that set them sharply apart from the physical sciences. This difference resides in the fact that the laws of physics are universal and coextensive with space. By contrast, biology in its very nature is earthly in origin and is very possibly peculiar to earth-type planets, that is, limited to a terrestrial sort of environment. In fact, most space biology hinges on simulating a terrestrial environment in an orbiting or cruising spacecraft. The isolation of certain variables in space biology in order to study their impact on living systems usually consists in reproducing the terrestrial environment *in toto* with the sole exception of the variable under study: zero $g$, for example. This *per se* places a severe constraint on space biology in all its forms, with the exception of exobiology and the search for extraterrestrial life. Thus, while the physicist and astronomer want to "get out into space" to study phenomena as they are, the biologist only wants to put his system there, enveloped in an essentially earth environment; once he has done this he has only learned how the living organism behaves in a selectively abnormal environment.

This basic distinction accounts for many of the differences between biology and its sister sciences in relation to the scientific utility of the space environment.

It follows that the contributions of NASA's space programs to the life sciences are not likely to be so novel and fundamental as discoveries in the physical sciences. Only in the case of the discovery of extraterrestrial life would one need to state an exception, and that discovery has a small and diminishing probability. Nevertheless, the possible fundamental insights that might be gained into the importance of gravity to physiological processes, to patterns of growth and development, and to the basic nature of biological rhythms could constitute notable scientific advances. Insights into human group psychology which might derive from appropriate study of small, varied groups of individuals in prolonged isolation may make a significant practical contribution to psychology, because compatibility is so important and so little understood at the present time. The potential use of satellites for earth monitoring seems likely to become a method of great importance in large-area ecology and may become a most successful method of surveillance of the use and misuse of environmental resources and of pollution. The spin-off in the development of delicate sensors, miniaturized apparatus and analyzers, and computers and the impetus to development of bioinstrumentation and biotechnology will clearly redound to the benefit of all biological experimentation.

An appropriate relationship between the programs and laboratories of NASA and the life sciences community in general, as recommended elsewhere in this report, will greatly strengthen research in the life sciences generally at a time when, for the most part, federal support of basic research is being diminished.

## NASA'S PAST ACHIEVEMENTS IN THE LIFE SCIENCES

Although we have not attempted a complete analysis of NASA's accomplishments in the life sciences, some examples of past achievements are worth noting. In radiobiology, the measurement of solar and cosmic radiation in outer space has revealed the presence of high-$Z$ particles, and their effects on the cells of the vertebrate body have been plotted. It appears that cells immediately traversed by such a particle are killed along the full course of its track. In other words, a column of cells one-cell wide in diameter is destroyed. The biological effects will depend upon the capacity of the body to replace the killed cells and upon the redundancy of such cells in the body. The possible importance of this finding in relation to prolonged spaceflight requires no elaboration.

A second notable finding, often overlooked simply because it is so obvious, and yet of the highest importance in manned spaceflight, has been the determination of man's ability to operate quite effectively and without ill effect in the weightless environment for two weeks. What damage has been incurred by the astronauts may be attributable more to lack of exercise and immobilization than to weightlessness itself.

The discovery that there is no life and almost certainly no water on the moon is of high interest and importance, especially when taken in conjunction with the demonstration that carbonaceous materials do occur on the moon. These are basic data important to the general theory of the origin of life. Negative findings should not be dismissed as of minor interest simply because they are negative.

This Committee has not compared the relative merits of NASA life sciences programs with those of other federal agencies. Difference in mission may well warrant difference in emphasis and difference in organization. We have recognized the constraints imposed during the first 12 years of NASA's existence by the enormous engineering requirements of a mandate to set a man on the moon. All else has been secondary to the success of that mission.

If Skylab, the space station and space shuttle, and the Viking project are to replace exploration of the moon as the spearhead of the exploration of space, it is a propitious moment and an urgent necessity to re-evaluate priorities. The scientific priorities clearly will fall more heavily henceforth on the life sciences than they did before the moon landing. The organization of NASA, the budgetary allocations, the advisory committees, the review of proposals for support, the selection and training of astronauts, the coordination of onsite life sciences programs, and the selection of experiments for flight are some of the major aspects that we have reviewed and that create in us some concern as a consequence of our review.

# 4 Organizational Structure for Space Biology and Medicine in NASA

Although the life sciences comprise less than 5 percent of the total NASA budget, their interest to both the scientist and the citizen transcends their budgetary allotment. It is important that the programs of NASA in space biology and medicine be organized for optimal function and interaction and be performed at the highest possible level of scientific expertise.

We find instead that the current organization of this program is diffuse, being scattered in three Offices* and several Centers.† It lacks unified direction or purpose, central leadership, and coordination. Although major scientific programs often require multiple foci of effort, the present fractionated responsibility in the life sciences programs of NASA frequently leads to uncoordinated and uninformed duplication of effort, as well as to serious omissions in important areas not

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*Office of Advanced Research and Technology (OART), Office of Manned Space Flight (OMSF), Office of Space Science and Applications (OSSA).

†Primarily Ames Research Center, Moffett Field, California; Jet Propulsion Laboratory, Pasadena, California; Langley Research Center, Langley, Virginia; and Manned Spacecraft Center, Houston, Texas.

covered by any one of the present programs. The on-site programs at different NASA laboratories are poorly coordinated. For example, the Biosatellite III program was assigned to the Engineering Section of the Ames Research Center. Many life scientists at Ames were not adequately involved, even though interested and qualified; and there was no communication with the Manned Spacecraft Center, where interested personnel were also located. Again, the 90-day isolation experiment conducted by McDonnell Douglas is operated under a contract with OART through Langley Research Center, where there is inadequate representation from biologists, psychologists, and clinical investigators. Groups at Ames and at Houston who are particularly interested in human biology have expressed distress that they have not been asked to participate in the study, which seems to be reduced to a test of engineering equipment. Similarly, at least three groups are currently involved in a study on the effects of weightlessness on skeletal (bone) mass and skeletal muscle functions, with little coordination or mutual knowledge of respective technologies.

It seems anomalous that the largest share of the funds supporting life sciences programs, those coming from the budget of the Office of Manned Space Flight, are not regularly allocated to the life sciences at all but depend upon the ability of the Director of Space Medicine to persuade staff directors with allocated budgets to support his recommended programs.

Advisory committees have proliferated greatly and appear to overlap in function; each of the three Offices establishes its own advisory committees and panels. The review of proposals for support is diverse and unequal, in part considered by advisory groups and in part contracted without external advice by the staffs of the NASA laboratories.

The selection and training of astronauts has heretofore focused on the vital need to produce test pilots for spacecraft. It must now shift to the selection of mostly scientist-astronauts and -passengers and the training of these for a variety of data-taking and monitoring tasks. The present structure of the astronaut training program does not seem to be suitable for the new objectives.

The foregoing strictures apply to the life sciences in particular, with programs both more diversified and more dispersed than is the case for most of the other scientific disciplines represented in NASA.

It is worthy of comment that the life sciences programs in NASA have failed adequately to enlist the active interest and participation of the scientific community at large. The outside proposals that are submitted for consideration, although large in number, represent only a fraction of the actual potential for supportive effort in the universities and only a fraction of the potential also for imaginative, relevant, and worthwhile new programs that would extend beyond those conceived by the NASA staff and its advisors.

The reorganization of the life sciences programs in NASA here recommended is designed to remedy some of these situations and to effect a necessary coordination in program planning and implementation. Such consolidation could well lead to significant economies.

## CONSOLIDATION OF THE LIFE SCIENCES PROGRAMS IN NASA

### Office of Space Biology and Medicine (OSBM)

Central to the mission of NASA are the support of man in space, studies to enhance his safety and to improve his performance, and the exploration, in both manned and unmanned flights, of space biology and extraterrestrial life. If the agency is to discharge these responsibilities effectively, there must be centralized responsibility and authority for program planning and execution, coordination, and evaluation.

To that end, it is the unanimous recommendation of this Committee that a new Office be created, an Office of Space Biology and Medicine (OSBM). It would be headed by an Associate Administrator for the Life Sciences, a man of scientific stature and broad perspective, who would be responsible for all research efforts in these areas, whether ground-based or conducted in space. This Office should have its own budget and discharge its operational responsibilities both by means of intramural research programs in the various NASA Centers and by a contract-grants program in the universities and in industry. A Life Sciences Advisory Board (LSAB) would be an integral part of this organization (see below).

Within the administrative structure of NASA, the Office of Space Biology and Medicine could be established as an Office coordinate with OART, OMSF, OSSA, and OTDA.* Within this Office there would be four Units or sections, one for

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*Office of Tracking and Data Acquisition.

each of the prime program areas and each headed by a Director with appropriate scientific background: (1) exobiology and planetary ecology; (2) space biology; (3) human biology and aerospace medicine; and (4) personnel health and environmental medicine.

The Committee is unanimous in its conviction that consolidation of the life sciences programs in NASA into a single operating unit is essential for the proper discharge of those functions. Similar but less specific recommendations have been made by a number of advisory groups which have addressed themselves to this problem in the past,* and the considerations which led to those previous recommendations are even more cogent today. A new dimension in the urgency of the problem has been created by the very success of manned flight and the enlarged necessity of supporting man in space in missions of increasing scope, duration, and programmatic content; by the growing organizational complexity of NASA and the resulting fractionation of effort; and by the reassessment of overall priorities imposed by present budgetary constraints.

Returning to the four Units in the Office of Space Biology and Medicine, their respective areas of concern are illustrated by the following examples of specific activities:

*UNIT I--Exobiology and Planetary Ecology*

*Exobiology*

- Prebiotic and postbiotic environment
- Extraterrestrial life, past or present
- Survival of terrestrial life in hostile environments
- Interplanetary space and the panspermia hypothesis
- Automated biological experiments for planetary landers

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*"Human Factors and Training," Working Group Report, October 1958. (Under Chairmanship of W. Randolph Lovelace II, reporting to the Special Committee on Space Technology under the Chairmanship of H. Guyford Stever.)

"NASA Bioscience Advisory Committee Report," January 1960. (Under Chairmanship of Seymour S. Kety.)

Report of Dr. Nello Pace, Consultant to the Administrator, October 1963.

*Biomedical Foundations of Manned Space Flight*, Report by Space Science and Technology Panel, President's Science Advisory Committee (PSAC), November 1969.

*Planetary Ecology*

- Surface environment of the moon and planets
- Contamination of the moon or planets
- Backcontamination of the earth
- Analysis of meteorites
- Earth resources and pollution; animal tracking and conservation

*UNIT II--Space Biology*

- Effects of weightlessness on plants, animals, and cells
  - Cellular proliferation and activity
  - Distribution of blood and body water
  - Vestibular studies on animals
  - Animal and plant development
- Circadian and other biological rhythms
- Radiation exposure
- Explosive decompression
- Food recycling and extraterrestrial cultivation

*UNIT III--Human Biology and Aerospace Medicine*

*Human Biology*

- Pilot- and scientist-astronaut selection and qualifications
- Man in space--clinical investigation
  - Circadian rhythms
  - Vestibular function
  - Tolerance levels for zero or high *g*, vibration, noise
  - Clinical investigation of flight conditions
- Human behavior in space capsule, extravehicular activity, or ground-based closed environments
  - Man-man interactions and closed-cycle living
  - Possible role of women in space
  - Man-machine interface
- Waste disposal and cabin bacteriology
- Life-support systems and cabin bacteriology
- Suiting and equipment design

*Aerospace Medicine*

- Preflight conditioning and early detection of disease
- Capsular epidemiology and immunity
- Flight monitoring of man
- In-flight human biology--data-gathering (see *Human Biology*, above)

Radiation hazard procedures
Respiratory and cardiovascular performance
Deconditioning and postflight management
Medical kit; permissible dosages

*UNIT IV--Personnel Health and Environmental Medicine*

*Personnel Health*
Pre-employment examinations
Health offices and medical care units at the Centers
*Environmental Medicine*
Identification and rectification of special industrial hazards

Biotechnology and instrumentation form an important part of OSBM. As recommended on page 48, this supporting function is best served if biotechnical personnel are associated with the specific disciplinary units proposed while maintaining good communication between the groups in different Units. The administrative structure of a biotechnology research group in OSBM that coordinates the life sciences program with physical science technology should be determined by the Associate Administrator, OSBM.

The Office of Space Biology and Medicine would thus bring together, restructure, and coordinate the currently fragmented life sciences programs in OART, OMSF, and OSSA. Its budget should be commensurate with its responsibilities.

## An Alternative Suggestion for a Central Coordinator for the Life Sciences

As a much less desirable alternative, in the event that a distinct Office does not prove feasible, the Committee recommends that a new position be established in the Office of the Associate Administrator, that of a Deputy Associate Administrator for Space Biology and Medicine. He would advise the Associate Administrator and the Administrator with regard to desirable specific goals, priorities, assignment of responsibilities to the several Offices and Centers, and organizational changes. He would advise the Administrator also with respect to budgetary allotments for the life sciences in the several Offices, considered in relation to their programmatic responsibilities, and devise mechanisms for the coordination of effort in the various Centers.

If the present Office and Center structure is to be retained, there must be a reassignment of operational responsibility. The lines of demarcation have been blurred, in the absence of such centralized coordination and control, and the three Offices have developed overlapping and duplicative programs, without adequate mutual information about scope and progress and, in some cases, even without knowledge that closely related efforts were in progress in other parts of NASA. It would be a major responsibility of the Deputy Associate Administrator for Space Biology and Medicine to review these programmatic responsibilities and to make appropriate recommendations to the Administrator with respect to their possible reordering along the lines of the Unit structure outlined on pages 20-22.

## THE CENTERS

Although each of the present three Offices concerned with life sciences has administrative responsibility for three to four Centers, to a considerable extent each of the Centers functions autonomously and serves as the geographic locus for studies sponsored by any one of the Offices. There is too little exchange of information between the Centers--and even less in the way of coordinated effort in the life sciences.

It is the view of our Committee that the specific responsibilities of each Center should be assigned in such manner as to bring together programs that would profit maximally from geographic proximity. One of the major long-term responsibilities of the Associate Administrator of the Office of Space Biology and Medicine would be to coordinate functions and to make such reassignments of specific programs within the individual Centers as may be necessary to that end.

An annual or semiannual in-house symposium on NASA life sciences programs is suggested. It could include reports from grantees and contractors.

## ADVISORY AND REVIEW MECHANISMS FOR THE LIFE SCIENCES

The mechanisms vary widely in the several Offices and Centers for (a) selection of life sciences research projects, both ground-based and for flight, (b) review of applications for contracts and grants, (c) selection of flight experiments, and (d) evaluation of progress on both extramural and intramural programs. There is a multiplicity of advisory committees in OART, OMSF, and OSSA, many of them with overlapping responsibilities and some of questionable effectiveness.

### Life Sciences Advisory Board (LSAB)

There is a pressing need for a central advisory committee with overall responsibility for the life sciences programs of NASA. This Life Sciences Advisory Board should consist of 10 to 15 life scientists, not themselves currently contractors, grantees, or full-time employees of NASA, who would be appointed by the Administrator or Associate Administrator from nominations made by widely representative scientific groups (e.g., National Academy of Sciences, American Association for the Advancement of Science, American Institute of Biological Sciences, Federation of American Societies for Experimental Biology). It should choose its own chairman. It is important to have the LSAB represent the full breadth of the life sciences.

The LSAB should provide a continuing review of the NASA life sciences programs and should periodically assess progress toward the selected goals. It should recommend priorities among proposed programs and, where appropriate, recommend the initiation of new programs. It should visit all the laboratories and attend symposia; and it should have the responsibility of making final recommendations for the award of grants, drawing upon the advice of disciplinary review panels (see below). It should serve to assure adequate coordination of the activities of the several Units and Centers involved in the life sciences. The Associate Administrator for OSBM and the Directors of the Units would work with the LSAB *ex officio*. If current NASA plans to establish a Space Programs Advisory Council (SPAC) materialize, its subsidiary advisory committee for the life sciences could be the Life Sciences Advisory Board here recommended. It is the unanimous recommendation of this Committee that, whatever the action taken on its primary recommendation (the creation of an OSBM), a Life Sciences Advisory Board is vital to the success of the program and should be implemented at the earliest possible date. In the course of time it would replace or coordinate the current advisory machinery.

## Unit Advisory Committees

Each Unit of the Office of Space Biology and Medicine could have its own advisory committee, with a member of the Life Sciences Advisory Board serving as Chairman and with the Director of the Unit serving *ex officio*. These committees would review plans and projects of the individual Units and evaluate applications for support (see below). Members would be approved by the Associate Administrator, OSBM, from nominations made by appropriate scientific societies.

## Review of Contracts and Grants to Outside Investigators

The life sciences program in NASA is strengthened by grants and contracts to outside investigators. These awards have two mutually supportive objectives: (a) to provide (mainly by NASA contracts) direct support of in-house programs at one of the Centers and (b) to carry out studies (mainly supported by grants) relevant to the mission of NASA but not currently in progress at any Center.

Involvement of the scientific community at large with the life sciences programs at NASA has been limited by certain aspects of the grant and contract procedures. Requests for proposals have often been issued with such short deadlines that insufficient time is available to submit a well-prepared proposal. The single-year commitment, while often extended on the basis of informal understandings, is usually not adequate to complete a project in the life sciences, which must often extend beyond a single year. The uncertainty of support beyond the single committed year discourages involvement of life scientists, particularly those of such stature as to be reasonably certain of support from other sources.

The long lead-time required for flight experiments, the possibility of their elimination from a project after considerable effort has been expended, and long delays even in those that eventually fly make such programs a poor risk for a young scientist who is concerned with establishing or maintaining his scientific reputation. To keep topnotch scientists interested in such tightly mission-oriented experiments, it seems essential that support for the direct mission-oriented work should include additional funds for studies of a more general nature, which would be mission-related but not tied to a specific flight experiment. This problem would also be solved, at least in part, by the proposed NASA Life Scientist program (see below).

REVIEW OF PROPOSALS FOR SUPPORT OF OUTSIDE STUDIES Whenever possible, the Unit advisory committees should review proposals for support of studies by outside investigators. When this is not feasible, for example because of the highly specialized nature of some proposals, *ad hoc* panels should be established, organized along disciplinary lines and consisting of scientists chosen for their expertise. The members should be appointed for definite, overlapping terms by the Associate Administrator of OSBM from nominations made by appropriate scientific groups. These panels should not duplicate the work of the Unit advisory committees. The panels would review proposals, recommend approval or disapproval, and rank those recommended for approval in order of priority for funding. These recommendations should be reviewed by the Life Sciences Advisory Board and be subject to final decision and formal award by the Associate Administrator, OSBM.

REVIEW OF CONTRACTS IN DIRECT SUPPORT OF IN-HOUSE PROGRAMS A steering committee should be formed to consist of the directors of the Units of OSBM, the directors of those NASA Centers with significant biological or medical programs (or the chief life scientist of each Center), and an approximately equal number of outside scientists to provide a balance of the necessary expertise. The function of the Steering Committee would be to make final recommendations on the award of contracts in support of in-house programs (drawing, where necessary, upon the advice of the disciplinary panels described in the foregoing paragraph), to assign among Units of OSBM responsibility for the funding of contracts, and to assign among the Centers the responsibility for supervision and monitoring of the contracts. It should also periodically review the progress of the contract work and make recommendations concerning extension and termination.

## Selection of Flight Experiments

The unique and most costly aspect of NASA science is the flight experiment. The selection of experiments for flight is therefore one of the most crucial decisions in the NASA life sciences program, especially in view of the fact that, as we believe, many of the biomedical and biological problems that are of concern to NASA can be answered by well-planned experiments on the ground. While many factors, such as the space required by a particular experiment and its readiness for flight at the scheduled deadline, must enter into the final choices of what experiments are to fly, greater clarification of procedure and better establishment of criteria are needed. Careful thought should be given to the mechanisms through which such plans are processed, and the LSAB should be involved in the final decisions.

## THE NASA LIFE SCIENTIST PROGRAM

For a variety of reasons, recruitment of personnel for the intramural life sciences programs of NASA has not been what might have been hoped. Programs must be instituted to facilitate recruitment. These would lead also to greater participation by the scientific community at large in space-oriented research.

The Committee strongly recommends initiation of a NASA Life Scientist program, analogous to faculty awards made by the American Cancer Society, the American Heart Association, the Health Research Council of New York, and the National Institutes of Health. Persons who receive this award should be selected on the basis of their investigative programs and their personal qualities and would spend no less than one third of their time (either four months a year or one year out of each three) at a NASA Center or field station. The presence of these highly qualified investigators at a NASA Center would in turn attract competent young investigators at the postdoctoral level, facilitate recruitment for intramural programs, and enrich the in-house programs at the Centers.

Applications would be submitted on behalf of the individual by his parent institution, would be screened by the LSAB or an appropriate subcommittee, and would be approved by the Associate Administrator, OSBM. Appointments would normally be for six years, renewable once, and would provide (a) salary at a level commensurate with the scale for the individual's rank in his home institution and (b) core laboratory support of $10,000, to be supplemented by appropriate grants or contracts, either from NASA or other agencies.

The initial scope of the program might be a total of 16 awards, increasing by perhaps 8 each year to a maximum of 40. The initial budget would thus be approximately $500,000, increasing to a maximum of $1,500,000 per year. The Committee is unanimous in its conviction that such a program would broaden and enrich the total thrust of the life sciences program in NASA to a degree far exceeding the relatively small funds involved.

# 5 Priorities in NASA's Life Sciences Programs

The life sciences most relevant to NASA's mission may be subsumed under four heads: (1) exobiology and planetary ecology; (2) space biology; (3) human biology and aerospace medicine; and (4) biotechnology and bioinstrumentation.

## EXOBIOLOGY AND PLANETARY ECOLOGY

### Exobiology

The search for extraterrestrial life has consistently figured prominently among the objectives of the space program. Interest in this question reflects man's age-old desire to understand himself, his origin, and his relation to the cosmos.

The great biological theory of the nineteenth century was the theory of evolution. It revolutionized biological thinking and redirected all biological investigation. Its spreading impact upon philosophical, religious, political, and social thinking has been matched by only one other scientific world-view--the Copernican theory, which displaced earth and man from the center of the universe. The theory of evolution made man no longer the special object of creation but a single--albeit a highly successful--species in the evolving web of plant and animal life on earth and a species, like all others, subject to the pressures of natural selection.

Darwin's theory of organic evolution did not, however, answer the question of the origin of life on the earth. During the present century, scientific developments have provided a coherent basis for postulating the origin of life, and ultimately of man himself, from a succession of chemical changes occurring during the natural history of the earth. According to this view, given the right environment and given time enough, life might be expected to evolve on any celestial body where conditions similar to those on the primitive earth prevail.

The search for life elsewhere, and the chemical steps toward life, is a part of the attempt to validate this theory. If substantiated even in small part, it may well have a major effect on man's view of himself and his universe, for a solution to the riddle of life's origins and an indication of its possible existence elsewhere in the universe at one and the same time make terrestrial life less unique and arouse the hope that we may someday communicate with intelligent life elsewhere.

Present research in exobiology can be divided into two categories--that requiring spaceflight and that which can be performed on earth. Ground-based studies are valuable both in their own right for fundamental inquiries and as precursors to spacecraft experiments. Laboratory studies explore the conditions that might be available elsewhere in the universe and that could give rise to chemical components and structural or behavioral attributes of life; included in this category are studies on the production of organic molecules from inorganic precursors and on the conditions leading to the formation of even larger structural units. Also relevant to exobiology are earth-based investigations of terrestrial organisms living under extremes of environmental temperature, pressure, moisture, oxygen, carbon dioxide, radiation, and other variables. NASA now supports research in all these areas. The research is inexpensive relative to flight experiments, and the scientific yield has been worthwhile. It is important that support for such work not be eroded.

The second category of exobiological research--that requiring spaceflight--is necessary to perform the definitive explorations and to provide definitive answers to the questions in exobiology. As yet, except for the moon and meteorites, where life is not to be expected and has not yet been found, no extraterrestrial body has been examined for living organisms.

This remains, therefore, one of the most important scientific goals in our exploration of other worlds. Furthermore, because this question can be studied only if artificial contamination by terrestrial microorganisms is avoided, precautions against this complication are called for in all explorations of planets where conditions suitable for the growth of terrestrial contaminants may prevail, irrespective of any other purposes for which the explorations may be undertaken.

From the foregoing, the following major questions emerge in our exploration of other planets: (1) Is life present, or has it existed there previously? (2) If so, what are its characteristics? (3) If not, is there evidence of prebiologic chemical evolution? (4) To what degree may the extent of chemical or biological evolution have been limited by local environmental conditions? What are the limiting conditions, and how are their effects mediated? (5) Can the environment, with or without modification, support terrestrial life? If so, can it be used as a laboratory for studying the evolution of life under different environmental conditions?

Within the universe, it is estimated that there may be thousands of planets with histories comparable with ours and conditions therefore compatible with life. Of these Mars is thus far the only planet other than earth that has become sufficiently accessible and that seems sufficiently hospitable to merit exploration at this time for living organisms. Jupiter and Venus are also of interest from the standpoint of prebiologic chemical evolution. On the moon, traces of several simple carbon compounds have been reported, and their existence suggests a pattern of chemical evolution consistent with the prebiologic changes predicted by the theory of biological evolution mentioned above. The absence of lunar life *per se* in no way diminishes the biological importance of these findings, if they are confirmed. Newly acquired knowledge of Venus and Mars, likewise, has reshaped our concepts of the environments on these planets and the types of biological studies that can be meaningfully attempted there.

Meaningful biological study of Mars or of any other planet requires, in addition to access, detailed knowledge of the surface environment. Since this knowledge is still highly limited and in a state of rapid flux, current research programs in exobiology are preliminary and must remain flexible.

These limitations notwithstanding, a substantial effort is now being mounted to explore Mars. The major objectives are: to investigate the physical and chemical conditions on the planet, including the organic chemistry of the surface material and the potentialities of the environment for life; to determine whether life is or has been present; and, if present, to characterize that life.

The effort required to pursue these objectives may surpass in magnitude and cost that of any biological project hitherto attempted. It is therefore appropriate that there be a continuing input from the scientific community in the selection and ordering of experiments and in the planning of experimental design and supporting equipment, as well as in the actual conduct of the experiment. The advisory committee structure outlined in Chapter 4 could contribute importantly in this respect. The strategy for such studies and the importance of these explorations are such that our Committee does not feel that it should prematurely speak on the basis of insufficient knowledge and competence or make detailed recommendations of priorities.

The exobiological research directed toward Mars is coordinated in Project Viking, which was formally organized in 1969. This project consists of an integrated series of complementary experiments now being planned by more than 60 scientists, from laboratories throughout the country, who are grouped into teams representing the various disciplines involved. As now envisaged, the project calls for launching two spacecraft, each consisting of a lander and an orbiter, the latter to assist in selecting the landing site and in relaying data back to earth. The data to be gathered are of many sorts: photographic, atmospheric, meteorological, geophysical, geological, chemical, and biological. The biological, or life-seeking, experiments include visual imaging, atmospheric analysis, organic analysis of the soil, and four different studies designed to detect metabolism or growth of soil microorganisms. We commend this approach. At the same time, we urge that the individual experiments be reappraised continually and be modified as necessary to ensure that their underlying biological assumptions remain valid in the light of new information about Mars supplied by the successive Mariner flights.

On reviewing the scope and accomplishments of NASA's research in exobiology, it is evident that many of the studies recommended in earlier reports* have been implemented or are being planned. The programs, however, suffer from insufficient overall coordination and from a lack of continuing detailed criticism by informed reviewers. In view of the importance and cost of Project Viking and related programs within life sciences, correction of these deficiencies by means of the changes in organization, planning, and review mechanisms, suggested elsewhere in this report, are urgently called for.

## Recommendations

1. Research in exobiology can conceivably contribute as much as any other aspect of space exploration to the expanding frontiers of man's knowledge of himself and his universe and deserves continued support as a major component of NASA's mission.

2. In the context of exobiological research, both studies on extraterrestrial chemical and biological evolution and complementary earth-based studies on the origin of life deserve sustained support. Funding for flight programs should not be allowed to encroach on the support of complementary ground-based research.

3. To improve the effectiveness of the studies in exobiology, especially in view of their importance and high cost, better coordination in planning and organization and improvements in review are urgently required.

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*Report of the National Aeronautics and Space Administration Bioscience Advisory Committee, S. S. Kety, Chairman, January 25, 1960.

*A Review of Space Research*, Publ. 1079, NAS-NRC, Washington, D.C., 1962.

*Space Research: Directions for the Future*, Publ. 1403, NAS-NRC, Washington, D.C., 1966.

*Biology and the Exploration of Mars*, C. S. Pittendrigh, W. Vishniac, J. P. T. Pearman, eds., Publ. 1296, NAS-NRC, Washington, D.C., 1966.

*Planetary Exploration 1968-1975*, Report of a Study by the Space Science Board, NAS, Washington, D.C., 1968.

*The Next Decade in Space*, A Report of the Space Science and Technology Panel of the President's Science Advisory Committee, Washington, D.C., 1970.

## OBSERVATIONS OF TERRESTRIAL BIOLOGY

The Santa Cruz study* has devoted attention to the significance of satellite-based studies for monitoring the migrations of birds and animals on land and in the oceans. Data telemetered via satellites, and in some cases aircraft, from sensors on animals should provide evidence sufficient to discriminate among the various hypotheses developed to explain the basic mechanisms of animal navigation and orientation.

Terrestrial ecology over wide areas may quite possibly be better sensed and studied from a single satellite than by even numerous observers on the ground. Instrumentation in this field should be developed rapidly. The monitoring of the effects of human management or misuse of environmental resources or of pollution, and the husbanding of resources, including endangered animal species, may in future come to depend heavily upon satellite-based observations. This is an area in which pure biology, applications, and biotechnology and instrumentation come hopefully together.

### Recommendation

1. The use of sensors on unmanned satellites for surveys of the earth should be explored and put to practical use when possible.

## SPACE BIOLOGY

Although it is evident that biological research is indispensable to the fulfillment of many of NASA's objectives, it is not nearly so certain that biological experiments conducted in space can contribute in a major way to our understanding of fundamental biology. Our Committee must further record its view that to date the organization, planning, and execution of this component of the life sciences programs of

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**Space Biology*, Report of a Study Convened by the Space Science Board, University of California, Santa Cruz (National Academy of Sciences, Washington, D.C., 1970).

NASA have not led to significant progress, and that a continuation of present patterns of program planning and execution does not offer the prospect of improved performance.

It is well to recall that the National Aeronautics and Space Act of 1958 calls for activities in space to be pursued "for the benefit of all mankind," and it lists as its first objective "the expansion of human knowledge of phenomena in the atmosphere and space." To date, the fifth objective, "the preservation of the role of the United States as a leader in aeronautical and space science and technology..." seems to have prevailed. The life sciences, save for the effort in exobiology, have thus been largely relegated to the role of a supporting facility needed to maintain functioning astronauts. The severe limitation of physical and financial resources indeed necessitates a continuing and discriminating review of priorities for proposed space biology. A major question is that of the value to be placed on space biology apart from the acknowledged priority of exobiology and the undeniable need to "qualify man for flight."

These matters have been surveyed recently in several studies, which notwithstanding the scientific expertise of the groups assembled as advisors, were all affected by the constraints imposed by the trichotomy of NASA's research structure. The PSAC report of 1969 confined itself to the "biomedical foundations of manned space flight," touching on exobiology and unmanned Biosatellites only peripherally; the Santa Cruz study of 1969 omitted exobiology and in large part the medical sciences. The PSAC report emphasizes the urgent need to learn more about the responses of man to the space environment, including physiological and adaptive changes, man-machine integration, and psychological and interpersonal reactions. The Santa Cruz study emphasizes five principal areas of interest: biological rhythms; cells, plants, and invertebrates in space; man and vertebrates in space; radiobiology; and animal orientation. In a 1970 Space Science Board summer study of NASA scientific priorities in the next decade, one panel among six was devoted to the priorities in the life sciences--but its mandate is from OSSA alone.

Although the space environment presents unique possibilities for biological studies, it poses severe limitations by unavoidable restrictions on observation, manipulation, and experimental control. In addition, biological research typically is complicated by the intrinsic variability of the living subject and by the necessity of maintaining the constancy of all external influences except that of the variable under test. Accordingly, many observations must be repeated in order to obtain a meaningful result; and one experiment often leads to another experiment rather than to a definitive answer to a problem.

For these reasons, the Biosatellite approach, as hitherto employed, seems inappropriate for most future biological research. Because of the vast cost, few Biosatellites can be flown, so that only a few experiments can be performed. Preparation and instrumentation for each experiment are time-consuming and expensive, and there has been a tendency in NASA to automate experiments unnecessarily. Experiments are therefore difficult to modify after instrumentation has been developed. There has been an understandable tendency to combine many more experimental approaches in a single experiment than is usual or desirable. The disappointingly meager results obtained in some Biosatellite experiments to date are in part attributable to these conditions. NASA must take the initiative in attempting to reverse those practices that actually impede research in space biology.

The space station, serviced by a shuttle, offers promising opportunities for the enlargement of space biology in the next decade. In particular, it should become possible for scientist-astronauts or passenger-scientists to make primary observations and to monitor experiments adequately. A well-functioning laboratory can be visualized that will permit biologists to execute their experiments along sound lines, with less poorly coordinated group research and fewer confusing observations made on a single overtaxed animal. Compromises in the planning and modification of protocols need not be imposed by engineering pressures, and experiments can utilize more conventional equipment and less demanding and costly instrumentation. The time lapse between the planning and execution of experiments can be reduced, with gain in scientific motivation. The investigator can monitor the experiments himself and modify procedures in the way so characteristic of basic research. Many simple physiological readings can be made on the human subject directly, without the need for the numerous expensive telemetering devices employed on primates hitherto. For example, collection of urine for chemical analysis, now so difficult to obtain, may be performed routinely. Studies of extended duration may be conducted, leading to new insights into reproduction and development. Many more diverse experiments would be possible. Finally, the need to instrument experiments will be reduced, and the decision as to which experiments are to be flown will no longer be based so largely on whether they can be automated.

The effective use of manned space laboratories will itself, however, require long and arduous ground-based preparations and pilot studies. It seems fair to say that even the enlarged facilities contemplated for doing scientific experiments in space cannot accommodate more than the final, definitive work; and that numerous prior studies under simulated space conditions, or terrestrial conditions lacking only weightlessness, must be earth-based. To use a metaphor, just as only the tip of the iceberg is above water and nine tenths is submerged, so only the ultimate experimental test of a long and large preparatory program deserves to be conducted in space. Biological experimentation in space should be limited to well-planned, decisive experiments of the broadest general significance.

In the view of our Committee, therefore, it is misguided to feel disappointment that various recommendations--not ours alone--properly insist that most biological experimentation supported by NASA should be earth-based. The final tests of hypotheses in space can never be made successfully unless that is so. To admit as much is not to denigrate the importance of the ultimate test under conditions of weightlessness or reduced gravity or other conditions that prevail in space. It is rather to keep the total program in good perspective, and to place priorities where they should fall if success is to be achieved.

We assume that both manned and unmanned spaceflights will continue. If so, exploitation of the uniqueness of the space environment should provide insights in a number of fields of biology, for there are several conditions that cannot be reproduced on earth, at least, now: (1) the absence of gravitational forces, (2) dissociation from rhythmic events attributable to the earth's rotation, (3) presence of unique forms of radiation, and (4) high vacuum. In addition, space exploration has stimulated interest in other conditions which can be reproduced and studied in ground-based laboratories, for example, the effects of (1) prolonged exposure to relatively high levels of radiation and (2) a particle-free environment. Other conditions created in the course of spaceflight are of biological interest and can be studied on the ground, for example, the biological effects of (1) artificial atmospheres and (2) a number of atmospheric contaminants.

We still do not know fully the extent to which gravitational forces influence intracellular events, alter or determine the degree and form of cellular proliferation, affect the growth and development of plants and animals, and participate in the physiological functions and responses of complex organisms including man. How and to what degree gravity has influenced the evolution of organisms may become amenable to study. A vast amount of research will be needed to describe the biological manifestations of reduced gravitational forces, and even more will be required to elucidate the mechanisms by which these effects are mediated.

We concur in the recommendation of the Santa Cruz study to examine the "long-term effects of weightlessness on the early development and maturation of organisms and the subsequent changes that may occur after return to the terrestrial gravitational field. For example, small vertebrates should be raised from fertilization or birth in a spacecraft and kept there under observation until, at maturity, they are returned to earth and examined for possible modification in their microscopic and gross structure or in their chemical composition and behavior." The entire stimulus-response system for gravity perception should be examined in terms of detection, transduction, amplification, and response.

Biorhythms occur in many living organisms, some with exogenous causes and others that may be endogenous. Not all the former are clearly attributable to the earth's rotation. Spacecraft make possible the study of these phenomena either remote from the earth or in atypical relation to the earth as in an eccentric orbit. Numerous and long-range studies, utilizing multiple species of plants and animals under various conditions and durations of spaceflight, would be required to clarify the issues.

The biological effects of radiation, including high-energy heavy particles (HZE) encountered in space, are of great interest and potential importance. Proper studies will require adequate fluxes of radiation in carefully controlled experiments employing a variety of biological test materials. To the extent that new and more powerful ground-based accelerators can duplicate the HZE flux in space, they should of course be utilized for preliminary studies. So often in the past, however, have new qualities and quantities of high-energy radiations been discovered in space that it seems to us to be dangerous to rely exclusively on ground-based simulations which may turn out to be inadequate.

For the foreseeable future, the number of good experiments proposed for spaceflight will greatly exceed the number that can be conducted. Therefore, experiments must be chosen wisely. An informed and critical group of scientists should participate in that selection to ensure that those chosen will give meaningful results, with broad significance for science as well as interest to narrow subspecialty groups. To the greatest extent possible, experiments in ground-based laboratories should be employed to prepare for and to ensure the success of flight experiments.

### Finding

Unique features of the space environment present numerous opportunities for biological research, but limited flight facilities and high costs severely restrict the number of experiments that can be performed.

### Recommendations

1. If a space station and shuttle become available, opportunities for biological experimentation in space will be enhanced and a space laboratory adequate for biological experimentation should be included.
2. Space-related biological research should be encouraged in the scientific community at large. The quality and feasibility of experiments proposed for spaceflights should be evaluated by the appropriate advisory committee of the Office of Space Biology and Medicine, and priorities should be assigned by the Life Sciences Advisory Board.
3. Ground-based research should be employed to the greatest extent possible to lessen the need for flight experiments and to ensure that those performed answer definitively questions that are significant and well formulated.

## HUMAN BIOLOGY AND AEROSPACE MEDICINE

### Man in Flight

That NASA is charged with the program of aeronautical development and science, as well as space programs, is sometimes overlooked. Nevertheless, flight within the earth's atmosphere is an important programmatic and budgetary part of NASA's total concern, and the biology of man in flight, whether subsonic or supersonic, is consequently not to be neglected.

Studies of the effects of high acceleration and the tolerance limits of the human organism in these respects, studies of acceptable ambient atmospheric pressures and relative composition of the gas breathed, studies of the auditory and general physiological effects of noise and vibration, and studies of the effects of exposure to ionizing radiation--all were undertaken before there was any manned spaceflight. Without the biomedical knowledge then accumulated, the early ventures of man into spaceflight would have been exceedingly rash. The heralded commencement of supersonic, stratospheric flights in aircraft requires further careful delineation of safety limits and long-term effects, as do the environmental effects of prolonged earth-orbiting flights.

Much of what is learned from carefully conducted studies of human physiology under the conditions of atmospheric flight will be immediately applicable to spaceflight, because in both cases passengers and pilots are prisoners within the confines of an artificially maintained environment, and their reactions to acceleration, to high sound levels, to vibration, radiation, and changes of biological rhythms may be very similar. An advantage of the aeronautical flight programs is that at present far larger numbers of individuals could be tested for tolerance and comfort limits than in the case of spaceflight. Hence the range and variability of human reactions to specific environmental conditions can be better evaluated.

Another aspect of the development of future aircraft and propulsion systems is that of their long-term effects on the environment, not only through continuing noise and pollution but also through possible changes of weather patterns, solar radiation balance, and climate. This calls for continuing and searching ecological study by NASA as well as other agencies.

## Man in Space

RESEARCH The life sciences program of NASA was initiated, and the bold plan to land men on the moon conceived and developed, during a time of expanding public commitment to science and technology. The linkage of these two areas accounted for the brilliant success of that venture, which was validated by such goals as national prestige, exploration of the unknown, and economic and technological progress. However, acquisition of medical or biological knowledge was not a major aim of the manned spaceflight program, and its contributions were largely in other areas. With a lunar landing accomplished, NASA is apparently ready to emphasize and implement its goals in the life sciences. This occurs, however, at a time when we face economic stress, reappraisal of national priorities, and curtailment of federal allocations for scientific research and training, in some areas quite drastically.

Under these circumstances, the scientific community is under the necessity to evaluate every scientific project in terms of its possible contributions to knowledge in relation to its cost. That kind of evaluation, which the scientist is best equipped to provide, is a necessary component in the final allocation of the national budget; and if the scientist fails to provide that evaluation, it will be made by others with less competence.

Three general types of biological research can be recognized in NASA:

1. That research, without regard to its general scientific value, which NASA needs in order to carry out its missions effectively and safely;
2. Experiments proposed for incorporation into a flight which is justified on other grounds, but in which additional information of scientific value can accrue at some acceptable increment of cost and effort;
3. Experiments in which the scientific value is so great, and so dependent on unique features of the space environment, as to constitute the only, or the major, justification of a space mission.

It is of particular importance to disentangle the three types of research in the area of manned spaceflight, which accounts for almost two thirds of NASA's budget and includes, in future approved or proposed missions, additional lunar landings, Skylab, space station and shuttle, and, ultimately, flights to Mars and Venus. Although argument continues about whether the national and scientific goals in space will be served better by manned or unmanned flights, it is in our view to be assumed that man will continue to play a prominent role in space, unless biomedical research or operational requirements clearly and unequivocally say otherwise or unless technological considerations prove it to be unfeasible or uneconomical.

We relate now to the categories given above:

1. Most of the cost and effort fall into this category, represented by the hardware and bioengineering development

necessary to maintain man in space safely and with maximum efficiency. By drawing on a vast store of scientific information in chemistry, physics, fundamental and applied biology, medicine, and aeronautics, accumulated throughout the world over many years, the Mercury, Gemini, and Apollo missions were successfully engineered to keep most of the stresses and environmental conditions within ranges familiar to aeronautics. They have demonstrated not only that man can exist in space but also that he can perform the necessary operational tasks of flight, maneuver the spacecraft, and perform the limited extravehicular activity required for preliminary exploration of the moon.

In this category also fall studies of two unique attributes of the space environment: weightlessness and radiation in amounts or kinds exceeding those experienced within earth's atmosphere. The biomedical consequences of weightlessness have been studied only preliminarily and have not always been clearly distinguished from the effects of other imposed conditions, such as immobilization. The same may be said of the effects of high-energy radiations, particularly particles of high atomic number, $Z$, and high energy, $E$ (HZE particles). These particles deliver, per unit time, about six times as great a dose in lunar orbit as they do within the earth's magnetosphere. Much still needs to be learned of the biological effects of HZE particles, particularly in relation to the dose rate, as well as the increased doses delivered during solar flares. Moreover, the effects of radiation have not always been properly distinguished from those of other flight conditions, such as high vibration during launch. Careful and more extensive work in these areas must still be performed.

If a decision is reached to undertake prolonged manned missions into space, the importance of these and other unprecedented problems in biomedicine, psychology, and human interaction can be expected to increase considerably, as will the programs of bioengineering, medicine, and applied biological and psychosociological research which will be required to meet them. In this area, biomedical expertise is involved not so much in establishing the mission and its priority as in defining the biological and medical problems, devising the most effective solutions, and evaluating and selecting the competence necessary to provide them. The justification for this type of applied research lies in its ability to answer specific questions. NASA would be well advised to plan its research program in this area around specific manned missions. The necessary research and development can then be marshaled to solve the particular biomedical problems identified as likely to arise during the course of these missions.

2. The second type of research--that mounted "piggyback" on a mission established for other purposes--is illustrated by accurate measurements of water and salt intake and output before, during, and after weightless flight. This minimal information was not obtained in the Gemini or Apollo missions; yet upon it depends an appreciation of one of the risks encountered in prolonged spaceflight, as well as the development of appropriate prophylactic or restorative procedures. (More elaborate measurements of these functions, together with studies on calcium balance and bone density, red-blood-cell mass and metabolism, energy metabolism, immunity, and vestibular and cardiovascular function, are planned for inclusion in Skylab.)

Similarly, neither Apollo, Skylab, nor the ground-based closed system study at McDonnell Douglas, has included objective studies of behavior, performance, and social interaction which are clearly of great significance in qualifying man for very prolonged spaceflight.

3. The third type of research in the life sciences, namely, that which is sufficiently important in and of itself to justify a mission, is not so likely to involve manned spaceflight, the great costs of which must be shared by programs with several purposes. Furthermore, for a clinical problem that can only be studied in space, the findings are likely to pertain only to that specialized environment. Questions of more general significance can usually be studied under terrestrial conditions. Thus, the ability abruptly to reduce gravitational effects in the physiologically important axis of the human body to zero by assuming a horizontal position, and to maintain it for prolonged periods by means of bedrest, coupled with the relative ease with which positive and negative gravitational forces of considerable range can be produced in that axis by means of the centrifuge, had already made available considerable information with respect to gravitational influences on intravascular pressures, cardiac output, cerebral blood flow, and respiratory function before the advent of spaceflight.

The Biosatellite programs were devoted almost entirely to the acquisition of fundamental biological information, Biosatellite III in particular to a behavioral, neurophysiological, circulatory, and metabolic study of a subhuman primate in space. It is difficult to justify the $40 million cost of the latter experiment. The Office of Manned Space

Flight did not request the study and showed little interest in the results. Considered solely as a contribution to fundamental physiological knowledge, the information to be obtained was not shown to be new and unpredictable nor to require environmental conditions that were unique to spaceflight and that could not be adequately simulated on the ground.

URGENT NEED FOR A COMPREHENSIVE AND INTEGRATED BIOMEDICAL PROGRAM The operational problems of future manned spaceflight and scientific experimentation will involve progressively more complex man-machine relationships and longer durations in space. It will be necessary to demonstrate that man is able to withstand the stresses and strains of a hostile environment and to function effectively and efficiently for long periods in relative isolation and confinement in a weightless state.

Review of reports of previous investigative committees, review of the present programs of OMSF, and a visit by Committee members to the Manned Spacecraft Center have left the Committee with the distinct impression that a *sufficiently comprehensive and integrated biomedical program in support and extension of man's activities in space does not now exist.* There is an urgent need to strengthen research efforts and coordinate them with the clinical, flight-surgeon type of operation which is now in effect. High-level coordination and direction of life sciences research is needed if these programs are to bear effectively on the problems of manned spaceflight. This point was stressed in the November 1969 PSAC report entitled *The Biomedical Foundations of Manned Space Flight.*

The success of the manned space program to date rests mainly upon the empirical determination, through successively longer flights, of human requirements and tolerance limits. In many respects this has been a risky procedure. The fact that we have been reasonably lucky so far should not lull us into a false sense of security. Although apparently successful thus far for flights ranging up to 14 days, unforeseen exigencies, reflecting the lack of a strong ground-based and in-flight research program, might have occurred in flight and could have been disastrous. Although engineering and other operational requirements of the missions may have placed severe limitations on biomedical studies in early flights, a different attitude with respect to the need for data on man in space might have permitted more observations to be made. We have detected some feeling that even those observations that were made on Gemini 7 and subsequent flights were not made available to NASA Centers or to the biomedical community at large, quickly enough or in sufficient detail.

As the duration of the flights and the number of astronauts increased, the requirements for life support became increasingly critical and complex. A hazardous one-gas atmosphere (100% oxygen at reduced pressures consistent with physiological requirements for a normal alveolar partial pressure of oxygen) was employed, despite cautions from the biomedical community, until disaster occurred on the launch pad at Cape Kennedy. Since then, a 60% oxygen-40% nitrogen atmosphere has been maintained until after launch. Despite plans to bleed off the nitrogen during spaceflight until a relatively pure oxygen atmosphere is attained, an appreciable amount of nitrogen has remained in the atmosphere inside the space capsule. This may have been an advantage in the light of subsequent physiological findings; but more research is clearly needed on the optimal atmospheres to be employed and on the contaminants and toxicity factors in spaceflight, especially in missions of longer duration.

In space biomedicine, as in medical science as a whole, there has been a regrettable tendency to isolate "clinical" or practical phenomena in man from "basic" biomedical studies. The experience of the past 30 years in universities and university hospitals has demonstrated conclusively that the two must be brought as close together as possible to achieve a maximum understanding and effective management of clinical phenomena and to give the basic biosciences a maximum impetus from human phenomena.

In the manned spaceflight program, the "clinical" component is the selection, training, in-flight management, and postflight study of the astronauts, who might indeed be termed "clinical astronauts." To date, this area has been managed on the basis of immediate practical requirements and has understandably sought to avoid any disturbance of the astronauts' piloting and engineering duties or capabilities. This regimen has resulted in the successful completion of many missions involving dozens of astronauts, but it entails a lack of information about certain important variables that affect the life processes of man in space.

The space counterpart of earth-based human biology consists of studies of man in flight or, when essential, of suitable animal experiments. It is of the greatest importance that these two areas, "clinical" and "basic," be closely intertwined in NASA, under unified leadership.

There are many obstacles to the joining of human biology and clinical medicine in the hospital and university, and those same obstacles are being experienced acutely in the space program. The clinician, watching over his patient--like the physicians responsible for the astronauts--may resent what appears to be the unwarranted intrusion of data acquisition into an otherwise straightforward, and relatively hazardous, procedure. On the other side, the biologist who is accustomed to the tightly controlled atmosphere of his laboratory may regard observations made on man as unscientific, uncontrollable, and irrelevant. The joining of these two approaches over the past 30 years has nevertheless provided profound insights into genetics, biochemistry, virology, neurology, and psychology and has contributed knowledge critical to successful management and care of the human subject. The application of these same approaches to the study of man in flight might initiate a whole new phase of human physiology and place the care and management of man in flight on a firmer basis. The empirical approach to biomedical safety and life support must now be supplanted by systematic basic and clinical research.

In the next incremental steps, flight durations will jump from 14-day Apollo missions to 28 and 56 days in Skylab A and possibly to 6 months in the space station. Missions to Mars or Venus will require upwards of 700 days. Although 14- to 18-day manned flights have been made without apparent serious detriment to the astronauts' health or deterioration of their performance, some significant changes in physical and physiological state have been noted, including losses in bone calcium, blood volume, red-blood-cell mass, fluids, and weight. If these (and possibly other biochemical changes not yet determined) were to continue over longer periods, they might exceed the capacity for homeostatic adjustment and lead to irreversible damage. The evidence that so little study has been devoted to the effects of prolonged flight leads one to suspect that there may well be numerous other changes that should be carefully monitored as the durations of flight increase. Until the causes and consequences of the changes already observed during 14-day missions can be identified, and possible remedies found, it would be wise to proceed with caution in planning manned spaceflights of long duration.

Tolerance limits for physiological and psychological stresses should be evaluated, and physiological and behavioral functioning should be assessed during simulations of operational tasks. Not only would this provide a better and more complete qualification for astronauts in space, but it should lead to better selection procedures for astronauts and passengers.

Extensive and carefully determined baselines should be determined for each astronaut, preflight and postflight (and it is hoped to some degree in flight); prolonged postflight observation is needed to detect possible long-term insidious effects. Such studies should have been done previously. Unless crucial observations might be made on the remaining Apollo missions, opportunities for many of these studies will now probably have to await Skylab A and the space station.

Implementation of these large-scale, demanding, but essential studies requires the functional and administrative unification of human space biology and clinical astronaut programs. Both activities must be conducted within the same administrative structure (Office of Space Biology and Medicine) and under the overall direction of an individual who appreciates the many interrelationships, cross-currents, and mutual contributions of the two programs.

PSYCHOLOGICAL PROGRAMS IN THE SERVICE OF MAN IN SPACE In the tight constraints of a confined microsociety (a maximum of three astronauts to date but with proposed extension to 20 or more in a space station), the life-support and operational requirements are so highly integrated, and so interdependent upon the individuals involved, that any exigency such as an accident, sudden illness, syncope or convulsion, nausea and vomiting, or psychological perturbation in one member could jeopardize not only the mission but the safety of the entire group.

The initial selection of astronauts will require new criteria, over and above those needed for choosing good test pilots. Tests for psychological stability and compatibility will be necessary, for selected mixed groups differing in respect to body size, metabolic performance, and sex ought to be compared. A strong program devoted to the problems of small-group psychology could provide essential underpinning for NASA's manned spaceflight programs and would also greatly amplify NASA's contributions to basic behavioral science. The 1969 report of the Space Science and Technology Panel of PSAC suggested that the phrase "to qualify man for space flight" implies "a detailed understanding of the unique capabilities and capacities of the human organism, of the optimal contributions of this organism to the performance of space flight with a wide variety of objectives, and development of a predictive ability for performance or response based upon pre-flight data." It stated baldly that the necessary experiments to "qualify man" for future spaceflight have not been performed either on the ground or in space. We add the essential element of psychological tests for fitness, for small-group living, and for cooperative work.

Recommendations

1. NASA should establish a strong research program, utilizing both basic and clinical approaches, to delineate man's qualifications for safe and effective performance in space. Such a program would profit by being closely integrated with the present flight-qualifying and medical operating unit which is charged with the selection, training, and health services of astronauts. The two programs should be functionally integrated, but not necessarily under the same directorate.

2. The research program should have three sections: clinical studies in man, man-oriented biomedical research, and animal bioscience. Problems arising in the operational arm should be referred to the appropriate research section for study.

3. The research program in the basic life sciences should afford a broad coverage of areas, including physiology, neurophysiology, neurology, biochemistry, pharmacology, physiological psychology, and social psychology, among others. The objective should be to establish baselines of expected activity levels and to investigate all types of variation occasioned by stressful stimuli and conditions.

4. Particular attention should be given to the study of three areas of responsiveness in the human organism: brain or central neural activities, autonomic nervous system activities, and somatomotor activities. Stress reactions are ordinarily expressed through one or more of these channels. Every effort should be made to find the fewest and most representative of these indicators that might be used as the basis for in-flight data collection and that could best be instrumented for flight experimentation. Specific attention should be given also to sociopsychological studies that deal with small-group interactions and that are of critical importance to the selection of small groups or teams of space travelers and to the maintenance of effective esprit de corps over long periods of physically and psychologically close association.

5. A strong liaison should be maintained with biological and medical communities in order to ensure that university and hospital groups are aware of the problems involved in manned spaceflight and of possible contributions they can make. Some of the proposed NASA Life Scientist awards should be made with this need in mind.

6. Strong liaison should be maintained between each NASA laboratory and others where work of a contributory nature could

go on, particularly in animal studies and basic biochemistry. Such studies might be sponsored by OSSA.

7. If OART continues large-scale simulation studies such as Tektite and the McDonnell Douglas study, close cooperation should be maintained in order that essential biological, clinical, and psychological features are incorporated in the simulations and that the results of the studies are promptly fed back to MSC, Houston.

8. Coordination of the life sciences programs of NASA at a high administrative level is essential to ensure the close cooperation and constant interaction in all operational and research activities in the life sciences and, in particular, the interweaving of the basic and clinical approaches to the support of man in space.

## BIOTECHNOLOGY AND BIOINSTRUMENTATION

The foregoing sections make apparent how close a relationship exists between the problems of technology and instrumentation, on the one hand, and the successful conduct of life sciences experimentation in space, on the other. Biotechnology and bioinstrumentation are involved in all research programs and in every administrative unit. Nevertheless, because of special aspects and warnings regarding deficiencies, it seems advisable to discuss these matters separately.

Remarkable achievements have in fact been made, but in general the results are dismayingly expensive and too often seem rather hastily improvised. Much of the fault for this lies with the biologists engaged in planning space experiments. Too often they provide inadequate specifications. Too often they change requirements at a late stage of design. On the other side, the instrumentation groups frequently tend, because of insufficiently precise specifications or overrefined limits of tolerance, to overdesign and thereby increase costs. The remedy would seem to lie in longer and more careful planning and preliminary pilot studies by the life scientists and in long-term research and development in biomedical technology and instrumentation.

The objectives of the biomedical technology and instrumentation programs at NASA are: (a) to develop life-support systems for manned spaceflight; (b) to support approved life science experiments and to develop techniques and hardware for their realization in flight as well as on earth; (c) to develop new technology to make new experiments possible; and (d) to provide an interface between the life scientists and the fast-moving technology front in the physical sciences in order to bring the latest advances into use in the space life sciences.

The present biotechnology and instrumentation programs at NASA are adequate for the immediate needs of the life sciences and have contributed importantly to the progress to date. The Committee feels, however, that in several aspects the biotechnology and bioinstrumentation activities need to be strengthened to meet the increased demands of the future.

THE COST In the bioinstrumentation area the facilities at NASA are excellent. The results are of good quality, but the cost is very high. As mentioned before, because of the need to miniaturize most flight hardware, the exacting quality control built into NASA specifications, the lack of preliminary information about design and packaging, and frequent changes in components and experimental approaches, the cost is orders of magnitude higher than would be required for similar earth-based experiments. This very high cost makes it mandatory that flight experiments involving instrumentation be carefully screened with respect to the need for the equipment, the value of the information to be gained and the prospects of success, and, in particular, to ensure that no flight experiments be undertaken the answers to which could be provided by earth-based experiments. In at least one instance (blood pressure determinations on man in space) plans are being developed to automate and telemeter, at an estimated cost of several million dollars, a measurement that an astronaut could learn to do with one hour's training.

TEAM WORK Engineers should be involved in the early phase of experimental design in order to select the simplest instrumentation for an experiment and to avoid costly overdesign. The instrumentation group must learn the basic principles of each specific experiment and deal with the problems of suitable components, structure, and packaging. Although general guidelines may be provided, the individual designer often lacks sufficient background information with respect to dynamic range, signal quality required, and suitable building blocks. This results in overdesign and high cost.

COMMUNICATION Discussion and exchange of information between technology groups at different Centers and with outside communities could be enhanced. Many universities have recently established biomedical engineering curricula in bioinstrumentation and with advanced facilities. Their participation in mutually interesting research would be beneficial. Such centers of research and learning could provide background knowledge, perform exploratory research, and stimulate university interest and participation broadly, as recommended in the November 1969 PSAC report.

PLANNING A large percentage of funding in support of the life sciences programs of NASA is spent on instrumentation, much of which uses common building blocks and design techniques. A planned research program to study, develop, or standardize sensors and transducers, micropower circuit design, packaging techniques, materials, data reduction and transmission, and the like, would effect economies.

A RESEARCH GROUP It is desirable to establish a biotechnology research group within the NASA life sciences program. This group would concern itself solely with general biotechnology and instrumentation. It could provide the initial consultation for all life science projects and could serve as an interface in the fast-advancing technological front with the life science experimenters, coordinate the information flow between Centers and other groups, and assist life scientists in the initial phases of designing experiments, as recommended by the Santa Cruz study.

## Applications of Biotechnology and Bioinstrumentation

A number of the contributions of NASA programs to the scientific community have been discussed in the 13 volumes of *Useful Applications of Earth-Oriented Satellites* (NAS, 1969) and in the September 1969 NASA report for the Space Task Group.* The technological and instrumentational applications derived specifically from NASA life sciences research can be grouped into three categories. These are:

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EXPERIMENTAL TECHNIQUES A few examples are: (a) The remote sensing and remote control of physical parameters, such as earth sensing of weather, water-flow patterns, ground temperature, vegetation, and forest disease; (b) telemetry and telestimulation of a living subject at a remote location (when properly designed instruments are attached to or implanted in a subject, such techniques may minimize interference with norman activities, simplify the experiment, and extend the useful period of observations); (c) signal-transmission and noise-reduction techniques.

INSTRUMENTS Many instruments developed for spaceflight experiments can be modified for life science laboratory work. These include: (a) sensors and transducers such as electrodes, pressure detectors, and light detectors; (b) analyzers--bacteria-counting units, gas chromatography and mass spectrography equipment; and (c) portable miniature instrument blocks--amplifiers, modulators, and recorders, for example.

LARGE-SYSTEM AND INFORMATION-ANALYSIS TECHNIQUES Besides useful computer programs, the methodology for complex data transmission, analysis, and extraction of signals from noisy channels is potentially useful for investigators in the life sciences.

The broad scope of application from this technology covers biomedicine and environmental control, such as water and air pollution, and many urban living problems.

## Recommendations

1. A research group should be established in the Office of Space Biology and Medicine to be concerned with long-term research in biotechnology and bioinstrumentation, and development in these areas, and to be available for consultation, advice, and collaboration.
2. University faculty and facilities should be involved more deeply in exploratory research.
3. Engineers should be involved in the early phases of experimental design and should be placed in the operational life sciences units as necessary.