Report on NASA Biology Program

Life Sciences Committee, Space Science Board, National Academy of Sciences, National Research Council

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This report is based on a review of the Bioscience Programs of the Office of Space Science and Application, National Aeronautics and Space Administration. The review of the Biology Program by the Committee on Life Sciences of the National Academy of Sciences was conducted in late 1967.

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NASA EFFORT IN BIOLOGY - JANUARY 1968 REVIEW

INTRODUCTION

The NASA has developed over the past five years, a large and varied program in biology and medicine as they pertain to space. It seemed to the Committee of Life Sciences of the Space Science Board that this biological program - specifically that portion located in the Bioscience Division of OSSA - should be reviewed at this time to ascertain whether the program is now fulfilling, satisfactorily, the principal biological goals of the NASA.

Although the Committee's attention was focused primarily on the OSSA Bioscience Program, it is acknowledged that other administrative segments relate to and interact with the OSSA effort to such an extent that our examination necessarily must range over parts of OSSA other than the Bioscience Division and must include some efforts in OMSF and OART as well.

Advice from the Space Science Board and from studies it has sponsored has been carefully considered and frequently accepted by the NASA in developing its biological program, although admittedly, not every such recommendation has been implemented. Principal guidance has come from the Iowa City Study of 1962, "A Review of Space Research," from the Stanford Study of 1964, "Biology and the Exploration of Mars," and from the 1965 Woods Hole Study, "Space Research - Directions for the Future," supplemented by numerous shorter reports focused on specific topics of timely interest. Of the seventy-one specific recommendations contained in the 1962 and 1965 study reports, by NASA's own count, its response has been to implement 48, to partially implement 19, and to fail to implement only 4. The Committee feels that a considerable history of the OSSA Bioscience Program personnel actively seeking SSB guidance, their patient and usually very effective provision of briefings and other types of information about program aspects, and their patently sincere attempts to profit from findings and recommendations which were developed, all served to encourage the Committee in the belief that a comprehensive review and appraisal at this time would be especially useful to the NASA.

The Committee has already become familiar with various segments of the OSSA Bioscience Program and this information was updated on 18 December 1967 by a full day of program review at the NASA Headquarters. On 27 June 1967, the Committee had met at the Marshall Spacecraft Center to be briefed on pertinent aspects of the Applied Apollo Program, viz., the planning for bioscience experimentation in the S-IVB Workshop. Earlier, the Committee had met at the Ames Research Center and there had the benefit of observing, first-hand, the more relevant parts of the ARC bioscience effort. In addition, most Committee members by virtue of their service on other SSB panels and on NASA committees have varying degrees of familiarity with particular aspects of NASA bioscience programs.

MAJOR GOALS

The Committee's review was conducted in the light of NASA's major goals as we see them for the bioscience area. These were first formally identified by a Space Science Board Summer Study in 1962. Two principal goals are:

1. To search for life in extraterrestrial environments, to study such life forms as may be encountered, and to study the organic chemical conditions of extraterrestrial environments in order to better understand the probable origin and evolution of all life on earth and extraterrestrial.

2. To conduct experiments on terrestrial life in space so that we may better understand basic functional and developmental life processes by studies which may exploit the unique conditions attainable only in a space laboratory.

Another objective has been to support man as a space traveler by: (a) assessing the hazards of manned space flight, (b) exploring the formerly unfamiliar physiological and perhaps psychological adaptations which may occur in space, and (c) devising life support systems and protective measures as may be required. This third objective is primarily the acquisition and application of biomedical or bioengineering knowledge. The objective is clearly essential for NASA's overall program. In the Committee's view, the first two stated goals are fundamentally much more important and should be accorded primary positions in NASA planning for its bioscience efforts.

The OSSA Bioscience Program has accepted as its responsibility, the fostering of fundamental biological research in three areas: exobiology, environmental biology, and behavioral or psychobiology. This is in good accord with the Space Science Board's identification of major goals.

The task components of the Bioscience Program arranged so as to correspond insofar as possible to major goals are as follows:

A. Exobiology

(1) Studies of environmental extremes tolerated by earth organisms.

(2) Laboratory studies of physicochemical processes, presumably relevant to prebiotic chemical evolution.

(3) Search for evidence of living organisms in material of meteoritic origin.

(4) Development of life detection devices for remote sensing.

(5) Research on decontamination methods and other techniques relevant to space probe sterilization and control of contamination (Planetary Quarantine).

(6) Support of planetary mission planning.

B. Environmental biology - broadly, the effects of the space environment on physiology and psychology.

(1) Studies on physiology and development (referred to as "environmental").

(2) Behavioral studies (psychobiology) including biorhythms.

(3) Support of Biosatellite and other flight programs.

(4) Physical biology - a heterogenous grouping of tasks in bioengineering, instrumentation, etc.

C. Bioscience communications - an effort to collate in up-to-date and useable form, the literature generated by and directly relevant to space biology.

D. Major flight programs.

(1) Biosatellite - operationally assigned to the Ames Research Center.

(2) Planetary missions - planning only.

ASSESSMENT OF PROGRESS TOWARD GOALS

The Committee regretfully recognizes that progress toward these major goals has been less impressive than had been anticipated. The first goal, conveniently subsummed under the coined word, exobiology, according to the Space Science Board's recommendation was to be the principal focus for concentration of NASA effort in planetary exploration during the post-Apollo decade. For reasons of scientific importance as well as urgency, because of potential contamination hazard, unmanned expeditions to Mars to gather scientific information with initial emphasis on biologically significant aspects were recommended for first priority in NASA planning. The record of progress shows:

1. Some reluctance on the part of NASA to implement an ambitious Martian exploration program promptly. Delays in marshalling resources, selecting an appropriate rocket

vehicle, and obtaining Congressional funding all resulted in NASA's inability to take advantage of optimal launch opportunities in 1969 and the early 70's.

2. Resources allocated to or recommended by NASA to be allocated to the "build up" stages of the planetary program were insufficient to initiate this important effort in an optimal way.

3. Progress in developing an appropriate payload for biologically significant experimentation from a Martian lander until very recently has been sadly deficient. Had there not been other more serious delays, payload development would now be the pacing item in scheduling a biologically significant planetary landing mission.

4. The acknowledged primacy of the Apollo mission - understandable and acceptable for reasons other than scientific seems to have established a philosophy that is carried over to an alarming degree in the Applied Apollo Program. It seems that NASA has paid proportionately more attention to the fifth objective of its Congressional charge, "The preservation of the role of the United States as a leader in aeronautical and space science and technology..." (interpreting this as a mandate to develop paramount capabilities for <u>manned</u> space flight) than to its first stated objective, "The expansion of human knowledge of phenomena in the atmosphere and space."

As we approach the post-Apollo era, the courses of future programs are necessarily being conditioned now, and it is quite apparent that planetary exploration (for biological as well as non-biological studies) has not been accorded a position of primacy in NASA planning. This observation applies also to the period before the present Congress withheld funding on major "new starts."

The NASA's reaction to delay but not cancel planetary exploration effort, to reprogram some money for planning, and also to continue the effort on space probe sterilization technology is commendable. Nevertheless, the lesson is clear; delay in initiating an ambitious program of planetary exploration was responsible for the vulnerability of that effort when economy considerations became paramount. At the root of the delay, we feel, was the internal competition for funds between the manned programs and space science. That this competition, which is itself natural and inevitable, was allowed to bring NASA's planetary exploration program to the verge of disaster in the planning stage is evidence that NASA's priorities should be re-examined in light of its Congressional charge and Space Science Board advice.

5. Planning for biologically significant planetary exploration has not been well coordinated. After identifying the principal objectives in its 1962 Review of Space Research (NAS-NRC, Pub. 1079, pp. 9-6 to 9-11), the Space Science Board sponsored a study in depth at Stanford during 1964-5, which was reported in "Biology and the Exploration of Mars"

(NAS-NRC, Pub. 1296). The scientific justification for a biologically significant planetary program was delineated along with general recommendations for developing a program. Implementation of these recommendations has been inadequate. Recently the chairman of the committee was advised of planning for a biological payload on the projected 1973 Mars Lander. However, NASA's internal machinery for developing biologically significant payloads for Martian Landers is still of doubtful adequacy.

6. The development of technology for building and launching sterile space probes and for related measures needed to avoid undesirable contamination of planetary objectives has proceeded satisfactorily, although not without temporary frustrations. Under the broad umbrella of NASA's interest in exobiology, this area, contamination control and sterility certification, stands out as an administrative and technical achievement. To bring together scientists and engineers with disparate backgrounds and viewpoints and to develop an ongoing program which could only succeed by cooperative efforts based on mutual confidence, respect, and understanding is no small accomplishment. Contributions of the group at JPL have been noteworthy and the Public Health Service personnel at the National Communicable Diseases Center in Atlanta have been especially effective. The Committee considers this an excellent example of fruitful interagency cooperation.

7. Most ominous are the persistent suggestions of scientists in and out of NASA to compromise the biological objectives of planetary exploration. By proposing the use of large payloads for Martian landers, necessarily launched by Saturn class boosters, the Standford study group made a well considered scientific and technical decision. The arguments now employed to revise that recommendation - viz. that smaller vehicles cost less and can be made available sooner---if allowed to prevail, will force a virtual abandonment of certain specifically biological objectives. Possibly, considerations having little to do with space science will determine the course of planetary exploration. However, we cannot pretend that such a compromise on the use of smaller vehicles and other payloads offers a satisfactory alternative to a biologically focused landing mission. If NASA planning continues in its recent direction, it should be recognized as departing, for whatever reasons, from the recommended top priority goal of exobiology.

8. Supporting research and technology which relates to NASA's goal in exobiology has been an impressive effort centered chiefly in the Ames Research Center and in several universities. In general, this program has attracted the part-time or, in some instances, full-time attention of scientists of high quality.

In summary, with regard to its first goal, exobiology, which includes the study of prebiotic chemical evolution and the origin of life as we know it, the strength of the present program lies in NASA's SR&T effort and in the development of sterilization technology. The weakness of the program lies in NASA's failure to translate its major objectives into a flight program which can do justice to its paramount goal.

The second major goal of NASA's effort in biological science to study environmental biology in space has been approached by concentrating on a series of unmannned flight experiments including mainly those of the Biosatellite series and by a general SR&T effort mostly at ARC and in a number of universities. Most of these research efforts directly or indirectly support flight programs such as Biosatellite. Some are so fundamentally oriented that potential application to flight missions is less evident.

In pursuit of this second goal, three problems were identified early in the development of the Bioscience Program which were of scientific importance: (a) the response (adaptation) of plants and animals (including man) to a condition of prolonged weightlessness, (b) the possibility of synergism (or antagonism) in the combined effects of weightlessness and ionizing radiation, and (c) the possible influence on circadian physiological rhythms when organisms are effectively isolated in space from factors related to the earth's 24-hour period of rotation.

The SR&T Bioscience effort in this area is generally commendable.

However, the Committee was aware of some weak spots and of elements which seemed only quite distantly related to NASA objectives. While the total program is understandably varied and even diffuse---for it is inevitable that a well balanced program must include facets not very directly related to flight missions---the Committee felt that a tightening-up could be beneficial. A general criticism noted by the Committee was that the major goals of the Bioscience Program do not clearly stand out when the SR&T effort is viewed as a whole.

Some members of the Committee considered the psychobiology portion of the Bioscience Program worthy of special comment. This is a difficult area to organize in terms of fundamental psychological objectives since we have too little experience in the unfamiliar environments of space to assess confidently where may lie the most significant fundamental research problems and the most important applications to manned flight. Presumably the most challenging questions relate to the possibility of deafferentation and its consequences with respect to vestibular and kinesthetic activities. In the remarkably short time of three years, NASA has developed a substantive SR&T program in this area and has brought a modest flight program into being. Surely this is an effort which must evolve as we learn more about the problems which are encountered and about experimental results which must be especially opportunistic. The present effort is at least off to a good start.

In Bioscience---more so apparently than in any other NASA scientific program---proposals for SR&T research support have been evaluated, at least in recent years, for their scientific merit by out-of-house panels of experts. The Committee feels this has been a commendable practice proven by the experiences of several more mature federal granting agencies as an essential device for insuring high scientific quality of the work supported. We believe that the OSSA Bioscience Program's use of non-NASA consultants also has effected a measure of liaison with the scientific community which will continue to pay a various indirect dividend to the NASA program. Aside from the advice given by the Space Science Board and its panels, the NASA bioscience effort has had the benefit of assistance from a number of advisory groups - AIBS panels, AIBS Regional Councils, AIBS Planetary Quarantine Advisory Committee, and the Interagency Committee on Back Contamination.

The major flight program in bioscience is the Biosatellite series now only 1/3 completed and presently subject to a discouraging "stretch out." It is still too early for the Committee to evaluate this program except in a very broad sense. Considering the goals of space biological research, it is apparent that the Biosatellite program was only a very modest beginning. So far, Biosatellite has been an operational success and technically, the first two flights were very creditable achievements (in spite of the one unfortunate failure to recover). A most disconcerting feature of this program is the lack of a follow-on. Unless NASA plans seriously to take advantage of what is learned in the Biosatellite series in areas of technology, logistics, and scientific team management, as well as scientific results, much of the scientific potential for relatively inexpensive unmanned biological payloads in orbit will have been lost by default.

Bioscience also has promoted much less ambitious flights by ballistic rockets, balloons, and piggyback experiments on Gemini missions. These latter have suffered variously since they were not mission-critical. The experiences of the few investigators who have attempted to engage in such piggyback experimentation has not been such as to instill confidence of potential experimenters in the exploitation of such opportunities.

In the Committee's view, the absence of a clearly defined flight program after Biosatellite is a matter of critical concern. Biologists are now looking to the NASA for opportunities to conduct observations and experiments on a variety of organisms in the weightless state (or at values of G other than unity). Fundamental research on gravity-organism interactions is essentially virgin territory as far as G values below one are concerned. The results could be very exciting and bioscientists are anxious to get on with the task of exploring this new research area. Environmental biologists now must design their experiments to fit the Applied Apollo Program based on a refurbished S-IVB fuel tank. This prospect is unattractive for many scientific efforts and to many biological scientists.

The Committee attempted to evaluate the adequacy of the S-IVB "Workshop" as a scientist-astronaut's laboratory and to assess its advantages and disadvantages. This task was not easy because NASA's current plans for implementing the Workshop concept may only point the direction for further development and may in fact be more flexible than now seems to be the case. However, based on what we have learned about the S-IVB Workshop, we were in essential agreement on the following points:

1. Management - It appears that the AAP management has not had the benefit of the level of biological research advice during planning that would have been desirable. The program seems not really research oriented and consequently it may not accomplish the research objectives of individual scientists. Most of the so-called "experiments" which already have been given flight priority are tests of equipment functioning, monitoring, and checking on or improving ways of completing chores of no scientific interest. Thus, Workshop habitability demonstrations clearly dominate. While these are recognized as necessary for engineering reasons, it seems equally important to demonstrate the scientific potential of this kind of laboratory in space and to include at a reasonably high priority some representative scientific experiments which will demand significant attention of a scientist-astronaut (not just pushing a button at some predetermined time after launch). At present, higher priority appears to be accorded scientifically uninteresting experiments (more properly termed "non-experiments") and anything of true scientific interest which may be proposed, it seems, will have to be done on the old familiar non-interference-and-if-time-is-available basis. The scientist who may be inspired by the potential of a manned laboratory in orbit also is interested in feasibility demonstrations---to decide whether it would be scientifically profitable to take advantage of the Workshop for his experiments or might only be frustrating to attempt to do so. Overall, we gain the

strong impression that the AAP as now oriented will accommodate science including biology only in an essentially piggyback fashion. That impression is unattractive to the working scientist.

2. The Workshop itself- The concept of making an ingenious conversion of a spent fuel tank and then trying to find things to do with it was a cart-before-the-horse tactic which has not led to an optimal design for manned experiments in space. The current workshop plan is a compromise which will not meet the needs of some important kinds of experimentation. It appears that the fuel tank conversion plan paid little heed to needs other than astronaut support and "housekeeping." The usefulness of the workshop for scientific experimentation is, at this stage, uncertain. Its potential should be re-examined critically and realistically by NASA. Recent contracts with industry for the design of a workshop in a dry-launch S-IVB have yet to be evaluated.

3. Crew - The current plan for scheduling astronauts' time in the workshop so tightly that every minute of a 14-hour day is allegedly accounted for is unrealistic and surely will have a detrimental (even disasterous) effect on the performance of experimental tasks, manipulations of equipment, and data-taking. Even more revealing was the contention that the AAP crew member's time is worth $1,000,000 per minute in orbit, so every minute of crew time must be utilized in the interest of economy! The Committee's concern was not with the correctness of the arithmetic but rather with the concept of impossibly tight scheduling of the crew's time. We believe this indicates that NASA management may not fully appreciate the intended role of scientist-astronauts. These men were carefully selected for scientific competence and given additional expensive training. They are expected to think, reflect, use insight and judgement, engage in creative effort, and not function merely as preprogrammed technicians.

The Space Science Board which has played a significant role in the scientist-astronaut program from its conception saw as its primary objective, the use of highly qualified scientists as scientists to carry out experiments and to make observations in space. Anything less than this will, in time, work against the program. NASA should redirect its thinking about how best to make use of its scientist-astronauts.

4. Relation to an optimally designed MORL - The S-IVB Workshop since it was orginally designed around the limitations of spent tankage and with emphasis on habitability rather than suitability for scientific experimentation, does not exhibit features of a manned laboratory in space which this Committee would consider essential. Had planning begun with a well considered list of scientific experiments and medical observations to be accomplished, and with the advice of qualified scientists working closely with design engineers, this Committee predicts that the resulting space laboratory design would not resemble the Workshop as it is now being developed. Therefore, the Workshop must be considered, at best, a step toward an adequately designed manned orbiting research laboratory of the future. It remains to be determined whether the dry-launched S-IVB design will sufficiently abet the effort to develop a MORL useful for biological and other kinds of research in space to justify the resources which NASA is expending on its development.

5. Relation to MOL - The Committee was less familiar with the Air Force MOL design than with the NASA S-IVB Workshop. However, we are aware of some areas of overlapping capability. While it seems that both agencies have valiantly avoided any serious duplication of effort, we wonder whether a concerted effort to fuse these programs as far as the vehicle is concerned would demonstrate that both programs could be accomodated with the same major flight hardware.
6. The Committee notes the statement and recommendations contained in a report of the President's Science Advisory Committee, "The Space Program in the Post Apollo Period," and endorses the recommendations contained in this report. Pertinent recommendations are included in Appendix A attached.

The Committee feels that a significant potential for fundamental experimentation on biological subjects in earth orbit lies ahead. With regard to what has been done already with Biosatellite and what can be anticipated from the flights which remain to be launched, the program has been heavily slanted toward a specific kind of radiation-weightlessness experimentation. The Committee agrees that information derived from such flights could be of far-reaching practical significance in relation to manned space flight, and recognized that this was a principal justification for the priority accorded these flight experiments on a variety of radiosensitive biological systems.

Biosatellite II results have revealed relationships between radiobiological effects and other space flight factors such as weightlessness, and the committee believes that further experimentation in satellites would be justified insofar as the relationships are basic. Such research ought not to be mission oriented in the sense that only the most fundamental studies are likely to contribute fruitfully and necessarily indirectly to planning for radiation protection on manned missions of the future. In view of the limited flight opportunities which were offered, radiation studies have received rather heavy emphasis - more, for example, than studies on fundamental physiological effects of weightlessness _per se_ which the Committee judged to be of major scientific importance.

Since a laboratory in orbit, whether manned or not, allows biologists to study effects of the so-called "G variable" continuously from near weightlessness to some ten's of G (with on-board rotation), it seems a regrettable deficiency that so little attention is being given to flight systems which can exploit values of G sensibly above zero.

The biomedical implementation of manned space flight, because of its special character, is considered a third area of interest in bioscience, an interest shared for the present by subdivisions of OSSA, OMSF, and OART. The necessary monitoring of astronaut condition in longer and longer flights has been in the nature of tolerance testing which the Committee regards as operationally desirable and necessary. For various reasons which the Committee understands but disagrees with, NASA has failed to make some potentially significant medical observations on astronauts. The manned flight program from its conception to well along into the Gemini series was geared to technological success, and scientific observations on astronaut subjects were not actively encouraged. The Committee notes that Mercury and Gemini were indeed technologically successful programs whose objectives were achieved without at the same time making possible significant contributions to human physiology, which would have required far better liaison between physicians, physiologists, engineers, and astronauts than was permitted at the time.

There are two main categories of interest in this area of applied science: (a) learning how to deal with special hazards of space flight, and (b) the general development of life support systems appropriate for the several types of missions planned. In the first category the salient areas are:

1. Radiation hazard.
2. Use of an unnatural atmospheric pressure and composition.
3. Danger of fire and fire control measures.
4. Physiological adaptation to weightlessness.
5. Psychological adjustment to space capsule environments.

It was the Committee's view that NASA has made some progress in each of the above areas but that complacency is not justified in any of them. The area in which practical problems are most difficult to assess in advance probably is the last mentioned and this is under study by a Space Science Board committee of eminent psychologists.

The first area, radiation hazard, is probably best understood on the assumption that we can extrapolate our extensive but earth-based knowledge of radiation effects on biological material to space conditions - a matter on which further Biosatellite studies may have much to tell us. A review of the general radiation hazard problem has recently been provided by a Space Science Board sponsored study (Radiobiological Factors in Manned Space Flight, NAS-NRC Publication 1487, 1967).

The item listed on which NASA has the poorest record is that on fire hazard. Experience can be a hard teacher and the Apollo 204

Accident was a lesson NASA must take most seriously. The agency decision to continue to employ a one-gas atmosphere in Gemini and Apollo spacecraft has most often been criticized by biomedically competent groups chiefly because of undesirable physiological or pathological sequelae which might be anticipated from the use of an atmosphere of pure oxygen. However, in addition to such criticisms, the increased fire hazard attributable to 100% oxygen has been stressed repeatedly[1,2,3,4,5]. Nevertheless, in the face of such clear warnings from the biomedical community, tragically serious errors in engineering judgement were committed. Most significant was the failure to recognize where the danger was greatest (launch pad) and to provide what could have been very simple fire control measures at the time of highest risk. The Committee cannot judge the extent to which recent changes in procedures and equipment may have lessened the risk to Apollo crew members nor can it endorse the continued use of a cabin atmosphere of pure oxygen at even reduced pressure in the Apollo program. If Apollo continues to employ a one-gas system, NASA should be under no illusions that this Committee sees any convincing justification for this remarkable position. We believe the earlier decision not to change to a two-gas system for Gemini and Apollo was a mistake attributable to failure of effective communication between engineers and biologists. Here is an example par excellence of how important inter-disciplinary cooperation may be and how serious can be the failure when it is not effective. We regret that adequate steps to correct this mistake have been so delayed.

The fourth area, adaptation to weightlessness, has been studied (observed) by the expedient of incremental testing of which we approve, by simulation, using various techniques which the Committee feels are grossly inadequate for most purposes, and by animal experiments which were too few and almost desultory in design. The Committee concludes that NASA is ill-prepared for any surprises which may arise in the course of longer and longer extension of man's stay in space.

In the development of life support systems, especially for flights of long duration, NASA efforts are underway in OART as well as in OSSA. On the special topic of regenerative systems for atmosphere control, efforts on physical-chemical regeneration and those on bioregeneration are now under consideration by a special panel of the Committee on Life Sciences. The report of that panel is in preparation. Only a brief comment here is in order. In each of the areas of developmental effort, projects are on a modest scale at the present time. Unless these efforts are increased, it seems unlikely that a flight qualified atmosphere regenerative system of any kind will be ready for use; for example, on a manned planetary mission, by the 1980's. Only the matter of water recovery seems in a well advanced state and even here serious problems remain.

Waste manangement systems, currently the responsibility of Biotechnology and Human Research (OART), are still of essentially primitive design. The importance of this area indicates that increased effort would be warranted. Unless progress is accelerated, it seems possible that waste management's systems for long duration space flight will be designed suboptimally and that problems will be solved by measures more expensive than necessary. A special panel of the Committee on Life Sciences is reviewing this area. Its report, now in draft form, will treat this topic in greater detail.

By attempting to synthesize a broad overview of the NASA effort in bioscience, the Committee was impressed with the curious way component responsibilities and activities have been distributed between OSSA, OART, and OMSF. The degree to which bioscience responsibilities are dispersed throughout the NASA organization is rather more understandable on historical than on logical grounds. While we are not disturbed by incongruities which are only apparent or merely superficial, we do feel that a more centralized coordination of NASA bioscience might offer advantages. That we were unable to review the salient aspects of NASA bioscience effort in a single program but had to consider a broad range of programs in three major NASA divisions even to do justice to our review of the OSSA Bioscience Program itself is symptomatic of the diffuse organization of the total effort. In spite of mechanisms to coordinate the separate efforts, it is our impression that coordination is cumbersome at best and that the NASA organizational structure with respect to biology is responsible for or contributed to difficulties which have arisen. Moreover, we anticipate that coordination of bioscience efforts will become an even greater problem in the future.

NASA should continue to develop its biological research program along fundamental lines. Necessarily, that development must be rooted chiefly, although not exclusively, in the academic community. A space research program in bioscience as well as in other fields can successfully involve university scientists only with due regard to the circumstances which make the universities an especially valuable national resource for research and trained personnel. To fully utilize this potential, NASA should be aware of factors which shape the image it presents to university scientists. For example, the industrial R&D contract format tends to ignore some of the important mores of universities and to disregard certain patterns well established in the academic research community. Special attention should be given to tangible as well as intangible aspects of the agency-scientist relationship if NASA is to continue to carry out space research in the university context. Management of the OSSA Bioscience Program has demonstrated an awareness of these requirements and has established relationships with the biological research community which should serve as an example to other subdivisions of NASA now less intimately involved with research in the universities.

FINDINGS AND RECOMMENDATIONS - As a consequence of the Committee's review of the OSSA Bioscience Program, we were able to enumerate a list of general findings and some specific recommendations which we feel are worthy of consideration by the NASA at this time. As was the case with the review process itself, some of the following has relevance to NASA subdivisions and programs, as space medicine, other than OSSA Bioscience.

1. Finding - Planetary exploration with initial emphasis on biologically significant studies with a landed spacecraft is the most exciting scientific challenge of the coming decade. Planning for Martian missions which should include landers of substantial scientific payload now is lagging. During a period when flight opportunities are restricted by unavoidable delays due to funding deficiencies, an acceleration of planning seems in order.

2. Recommendation - The effort to develop a planetary-landed payload large enough to accomplish important biological objectives should be greatly accelerated.

3. Finding - There does not appear to be a flight program adequate for biological science after completion of the current Biosatellite series.

4. Recommendation - Planning should be accelerated on an urgent basis for the development of a follow-on unmanned flight program to supplement the current Biosatellite series. Presumably, a follow-on program could be based on vehicles which would impose less serious constraints on experimental designs than was the case with Biosatellite.

5. Finding - Studies on radiation biology in space, begun in a preliminary way on Biosatellite, are justified as manned mission related but they also could have fundamental significance.

6. Recommendation - The results of radiation experiments carried out on Biosatellite II should be carefully examined, especially with respect to their fundamental biological implications. If thorough appraisal indicates the need for further studies of radiation effects in the weightless environment, new and more sophisticated experimental designs should be undertaken.

7. Recommendation - Both projected flight programs and SR&T efforts in environmental space biology should be re-evaluated internally by the Bioscience Division to focus more effectively on the salient problems which can be studied uniquely in orbiting vehicles - specifically, those problems which relate to the weightless environment.

8. Finding - The OSSA Bioscience Program in environmental biology has need of both manned and unmanned flight programs in order to fulfill the NASA obligation in this area.

9. Recommendation - When biological experiments are carried out in a manned vehicle, they should be on board only if (a) they have survived an adequate screening by a panel of scientific peers, (b) they are classified as mission critical, and (c) they are classified as experiments for which a principal investigator accepts scientific responsibility.

10. Recommendation - The Bioscience Program involving manned vehicles should be re-evaluated with respect to exploitation of AAP. A guiding principle should be to avoid piggyback research in manned systems. As an occasional expedient, piggyback opportunities can be utilized effectively if investigators are willing to accept the attendant risks, but this method of implementing an entire flight program should be subjected to careful scrutiny at this time.

11. Finding - Committee members' evaluations differed with regard to the adequacy of the S-IVB Workshop as a manned laboratory in space. In its initial version, it is a patently suboptimal solution of the problem of providing

a laboratory for research by scientist-astronauts. Its potential for improvement remains uncertain.

12. Recommendation - NASA should support small scale, but intensive studies, to determine if experimental needs in space biology can be accomodated in configurations of the S-IVB.

13. Recommendation - The AAP should be carefully re-examined in light of Bioscience objectives and requirements in biology and space medicine.

14. Finding - The overall NASA effort in biology and space medicine is administratively fragmented. If reorganization is considered, it would seem desirable to achieve a more centralized organizational structure which could insure effective cooperation between life scientists and supporting engineers.

15. Recommendation - The current status of effort on development of regenerative life support systems - both biological and physicochemical - should be increased. None of the existing approaches are well enough advanced to warrant complacency.

16. Finding - The NASA program in human physiology is not being supported at a level consistent with the need for information relating to the effects of the space enviornment on man in long duration missions.

17. Finding - It is not apparent to what degree the Air Force MOL and the S-IVB Workshop are redundant; neither is it clear how much redundancy is justified by program requirements.

18. Recommendation - Planning for a manned orbiting research laboratory more ambitious than the S-IVB Workshop should be undertaken from the standpoint of experimental requirements as they may now be anticipated.

19. Finding - It would be well for NASA to re-examine its pos tion with respect to support of fundamental SR&T research in biology. Unless strong support is maintained, the future of this area as it relates to biological research in space will be in jeopardy.

20. Recommendation - A substantial fraction of OSSA Bioscience SR&T funds should be allocated to fundamental research in broad areas of NASA biological cognizance. As much as 20% would be justifiable. Such basic or pioneering research would not be obviously mission oriented.

21. Finding - The OSSA Bioscience Program has developed an essential interface with many relevant segments of the scientific community. It is important that these relationships be preserved and expanded. A major handicap which NASA encounters in developing a more vigorous program in Bioscience now relates mainly to the paucity of attractive flight opportunities which can be foreseen.

References

1. SSB Report of "The Working Group on Gaseous Environment for Manned Spacecraft," March 15, 1965.

2. SSB Summary Report of "The Man in Space Committee," January 1964.

3. Lovelace Foundation Report to NASA on "Fire and Blast Hazards," by E. M. Roth, 1964.

4. NRL Report 6470, "Flammability in Unusual Atmospheres," by J. E. Johnson and J. F. Woods, October 31, 1966.

5. Chapter 14, "Inert Gases," by W. O. Fenn of a report of a 1966 Summer Study on "Physiology in the Space Environment," NAS-NRC Pub. 1485B, 1967.

The recommendation quoted below which is from the Report of the President's Science Advisory Committee entitled, "The Space Program in the Post Apollo Period," prepared by the Joint Space Panels in 1967, is concurred in by the Committee on Life Sciences of the Space Science Board, National Academy of Sciences.

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> We recommend that NASA study the advantages of adopting a planning and decision-making structure which emphasizes program objectives rather than the means used to attain them.

The Committee on Life Sciences did not review the program in the Office of Advanced Research and Technology and in the Office of Manned Space Flight at the December 1967 meeting.