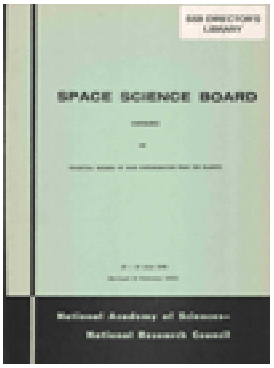

Conference on Potential Hazards of Back Contamination from the Planets

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

ISBN: 0-309-12378-X, 86 pages, 8 1/2 x 11, (1964)

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

CONFERENCE

ON

POTENTIAL HAZARDS OF BACK CONTAMINATION FROM THE PLANETS

29 - 30 July 1964

Dr. Allan H. Brown, Chairman

(Revised 19 February 1965)

Space Science Board
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C.

ACKNOWLEDGEMENT

The Chairman of the Conference on Potential Hazards of Back Contamination from the Planets, Dr. Allan H. Brown, wishes to express his appreciation to the following participants in the meeting who made substantial contributions in the form of background material and other data which proved of great value in the deliberations of the conferees: Dr. Franklin P. Dixon, Lt. Col. T. C. Evans, Dr. Verne C. Fryklund, Dr. S. J. Gerathewohl, Mr. Lawrence Hall, Dr. Orr Reynolds, and all others who assisted with this conference.

PREFACE

On 29 and 30 July 1964, a Conference on the Potential Hazards of Back Contamination from the Planets was convened at the National Academy of Sciences, Washington, D. C. The objective of this Conference was to discuss the possibility of returning space missions bringing back to earth organisms that might prove to be harmful.

The possibility of extraterrestrial life entails the chance that organisms might be returned to earth with returning space missions. The likelihood of this eventuality, and appropriate methods to deal with it, have been of continuing concern to certain members of the scientific community. The Space Science Board has long felt an obligation to be alert to the problem. In February 1960, a committee of the Board drafted a resolution urging that the matter be given attention. The subject was also considered during the 1962 Iowa City Summer Study.

The Life Sciences Committee of the Space Science Board held a two-day Conference on the Potential Hazards of Back Contamination which was attended by 30 specialists drawn from scientific institutions, government and universities. Presentations on NASA plans for planetary exploration and other background data were made to the conferees by NASA personnel.

A summary of the discussion of the Conference is given, which is followed by its recommendations and conclusions.

ATTENDANCE:

Life Sciences Committee:	Dr. Allan H. Brown, Chairman Drs. C. O. Chichester, George V. LeRoy and Wolf Vishniac[1]
Participants:	Dr. Gaylord Anderson, School of Public Health, University of Minnesota Dr. C. Robert Austrian, Department of Medicine, University of Pennsylvania Hospital Dr. H. Keffer Hartline, The Rockefeller Institute, New York City Dr. Lawrence B. Slobodkin, Department of Zoology, University of Michigan
U.S. Department of Agriculture:	Dr. Herman A. Rodenhiser, Agricultural Research Service
U.S. Army:	Dr. Charles R. Phillips, U.S. Army Biological Laboratories, Ft. Detrick, Maryland
National Institutes of Health:	Dr. Norman B. McCullough, Division of Allergy and Infectious Diseases
U.S. Public Health Service:	Dr. David E. Price, Deputy Surgeon General Dr. Simon P. Abrahams and Mr. Charles Weaver, Radiological Health Mr. E. J. Herringer, Division of Environmental Health Dr. Keith H. Lewis, Robert Taft Sanitary Engineering Center, Cincinnati, Ohio Dr. S. W. Simmons, Communicable Disease Center, Atlanta, Georgia Dr. Joe L. Stockard, Foreign Quarantine
National Aeronautics and Space Administration:	Dr. Oscar E. Anderson, Office of International Programs Dr. Carl Bruch, Mr. Lawrence Hall, Dr. D. W. Jenkins, and Dr. Orr Reynolds, Bioscience Programs; Dr. Verne C. Fryklund, Lunar and Planetary Programs; Dr. S. J. Gerathewohl,[2] Manned Space Science Division; Office of Space Science and Applications

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[1] Paper by Dr. Wolf Vishniac, "A Model of Martian Ecology"

[2] Paper by Dr. S. J. Gerathewohl, "Plans for Sample Collection and Return"

National Aeronautics and Space Administration: (Continued)	Dr. Franklin P. Dixon[3] and Lt. Col. T. C. Evans, Advanced Manned Missions Program; Dr. Mae Link, Medical Operations, Aerospace Medicine; Dr. Sherman P. Vinograd, Space Medicine Division, Office of Manned Space Flight.
National Academy of Sciences:	Dr. Paul E. Johnson, Food and Nutrition Board Drs. Sam F. Seeley and O. E. Van Der Aue, Division of Medical Sciences Dr. Herbert G. Shepler, Secretariat, Space Science Board

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[3] Presentation by Dr. Franklin P. Dixon, entitled "National Aeronautics and Space Administration Manned Planetary Studies"

Immediacy of the Problem

While much thought and effort have been devoted to the detection of extraterrestrial life and to precautions against contaminating it by terrestrial organisms, much less concerted consideration has been given to the converse problem of back contamination. The complex nature of policy planning, intercurrent research, and the design and construction of suitable equipment requires that considerable lead time be allowed for their effectuation. United States planning for roundtrip missions to the moon and planets has reached an advanced stage; the first manned missions to the moon are planned by the National Aeronautics and Space Administration for 1969, and the first manned missions to Mars will be possible no later than the mid-1980's. Consequently, an evaluation of the likelihood of back contamination, the seriousness of the threat, and of means of protection against it should not be postponed.

Possibility of Life on the Moon and Planets

The existence of life on the moon or planets cannot, in the Conference's opinion, rationally be precluded. At the very least, present evidence is not inconsistent with its presence. There is substantial agreement among scientists that the origin of life is a general process which can begin wherever certain preconditions of elements and temperatures obtain. The physical conditions, insofar as they are known, on Mars, Venus and the moon, indicate that life could have developed on the Martian surface, the Venus cloud layer, or in the lunar subsurface. Evidence suggests that the probability of life on the moon is low, rather unlikely on Venus, but not unlikely on Mars. Conclusive answers may not be obtained for some time. In the interim, however, negative data will not prove that extraterrestrial life does not exist; they will merely mean that it has not been found.

As a result, the Conference was unanimous in agreeing that extraterrestrial life and the concomitant possibility of back contamination must be presumed to exist. To presume otherwise could lead to inadequate planning of precautionary measures and failure to foresee a danger which might be avoided.

Potential Hazards of Back Contamination

The possible hazards of back contamination cannot, of course, be assessed on the basis of direct experience with extraterrestrial life. Rather, it is necessary to draw upon experience with destructive terrestrial biological agents and, from this knowledge, to attempt to forecast the worst conditions that might be faced. Innumerable examples of the harmful spread of biological agents exist. Pandemics of plague, smallpox, and yellow fever are well known historic facts. More recent examples are the spread of tuberculosis through the Eskimo population, the 1918 influenza epidemic, and the hundreds of thousands of malaria deaths in Brazil resulting from the transmission from Africa of the Anopheles gambiae mosquito. Crop plants also have been subject to attack. The best known example of such an agricultural disaster resulted in the "potato famine" following widespread fungus infection of potatoes in Ireland in 1845-1860.

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Policies of defense against back contamination must be based on the proposition that if infection of the earth by extraterrestrial organisms is possible, it will occur. Decontamination methods can reduce the number of viable organisms almost to zero, but since they are based on the logarithmic order of death, it is both mathematically, and in practice, impossible to reach zero. Therefore, the objective of defensive measures cannot be to prevent for all time the introduction to the earth of extraterrestrial organisms but rather to protect the earth from immediate infection. Over the longer term, as the nature of the exotic organisms becomes familiar, devices such as vaccines or some means to destroy the microbes can be developed. Ultimate protection against possible savages of exotic life forms may be in some sense their domestication.

Protection against back contamination from early planetary missions will be facilitated by the fact that the organisms will be confined to one source: the spacecraft and its occupants. If organisms can be isolated, they can be controlled. The Conference identified four possible sources of contamination:

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As stated by the Bioscience Panel of the NASA Apollo Science Team, "Lunar organisms, even if not inherently pathogenic, could, acting in conjunction with terrestrial organisms in the nose and throat of an astronaut, produce disease. Since such a symbiotic relationship would depend on the organisms normally found in the respiratory flora of different persons, one could equally well conceive that, while the astronauts themselves might not possess the proper combination for activation of lunar organisms, they could transmit such organisms to other persons whose nasal flora do contain suitable symbiots. Under such circumstances, one would have to be alert to the possible significance of any illness occurring among the astronauts or among persons in contact with them."

Back contamination from Martian missions is far more probable. Life, if it does exist on Mars, will be pervasive rather than confined to the subsurface. Each of the four sources of contamination thus must be considered possible. The Conference stressed, however, that the danger of back contamination from the moon ceases to be a danger only if there is no lunar life. Accordingly, defenses attending the first mission must be at their strongest, for the least will then be known concerning the hazards of lunar biological conditions.

a. Quarantine

At the outset of discussions on quarantine as a defense against back contamination, the Deputy Surgeon General of the U. S. Public Health Service stressed, "We must make an arbitrary approach to quarantine, but must also realize that quarantine is a crude concept and a crude approach to a problem of this sort. I would not feel safe in placing a large part of my faith in it as a security method." The value of quarantine in preventing the spread of disease is limited and far surpassed by that of vaccines and immunization. Conventional protective measures presuppose known diseases, with known symptoms and incubation periods. The nature of extraterrestrial pathogens is unknown; it is conceivable that there would be no observable symptoms or that disease would not develop for a considerable period. It is impossible, therefore, accurately to predict the type or duration of quarantine required. The Conference agreed that it is nevertheless a necessary first step.

The quarantine should be of the kind defined as "strict," as imposed for highly infectious respiratory diseases. The preferable duration is more difficult to determine. It should err on the side of conservatism, as judged by a knowledge of terrestrial diseases, and yet ought not to be unreasonably cautious, to the possible detriment to the mission and undue hardship on the astronaut. After much discussion, a duration of three weeks was recommended. The Conference was not unanimous in this recommendation: A minority of the participants favored extending the quarantine to four or even five weeks. The three week quarantine must therefore be considered a minimal precaution.

Since the risk of introducing a pathogen for man is greatest at the time the astronaut leaves the lunar or planetary surface and decreases each day that he remains healthy, the quarantine for lunar missions should begin immediately upon takeoff from the moon. The long return time from Martian missions (minimum 150-200 days) itself constitutes an extended quarantine. However, further considerations apply in Martian missions. The fact that the astronauts were healthy at return would not assure that the Martian organisms were not pathogenic. It is possible that while immune themselves, the astronauts could act as carriers of disease. It is also possible that the organisms could be harmful to terrestrial plants and animals. Consequently, the Conference felt that the same quarantine restrictions applying to lunar missions should be imposed for Mars.

b. Isolation of samples and spacecraft

Procedures being developed for scientific purposes to isolate samples from the time they are collected on the moon or Mars are essential also from the standpoint of back contamination. The proposed steps bear repeating:

1. Astronauts should be trained in clean-and-sterile techniques.
2. Samples should be immediately placed in sterile containers and perfectly sealed.
3. Within the spacecraft the samples should be strictly compartmentalized from the rest of the capsule and its inhabitants, and should not be removed until return to earth.

The Conference stressed that, upon return, the samples should be received into an isolation environment, being examined only behind absolute biological barriers, and should remain there for the duration of the quarantine under rigid bacterial and chemical isolation. Owing to the scientific and protective importance of such procedures, immediate steps should be taken to perfect the detailed operational techniques required for sample collection, storage, and examination.

Isolation of the samples on return must not, however, prevent their immediate examination. Data concerning their pathogenicity must be obtained at once. Moreover, since the usefulness of samples for certain tests, such as radio-isotope studies, deteriorates with time, to delay their analysis could impair the scientific value of the mission.

The spacecraft itself should be received into an isolation environment on board the aircraft carrier immediately upon recovery from the sea. The number of persons permitted to come in contact with the capsule - raising it from the ocean, securing it to the deck, assisting the astronauts to get out - should be kept to an absolute minimum and be required to undergo quarantine. The complexity of the operation and the specialized logistic requirements of an isolation environment are such that, in the Conference's view, detailed study of the problem should not be postponed.

c. Prevention of contamination

Although it will not be possible entirely to prevent contamination of the mission if contamination can occur, it should be possible by preventive technique to reduce substantially the number of contaminants. Every contact with the extraterrestrial environment is a potential source of pathogens; therefore the effectiveness with which each contact can be severed before leaving the environment will decrease the contamination.

In collecting samples, astronauts should be trained in clean-and-sterile techniques so as to avoid the spread of contaminants which may be present. Despite plastic shields on hands and feet to be discarded when astronauts re-enter the capsule, some particles from the lunar or planetary surface which have adhered to their clothing or equipment almost certainly will be introduced inadvertently into the capsule. Techniques to minimize this major source of contamination should be developed. The Conference recommended that three areas of research be utilized:

1. Studies already underway in other fields should be examined for their potential relevence.
2. A study specifically designed to expose problems which may arise in space missions should be initiated.
3. A trial run with capsule and astronauts should be carried out using non-pathogenic organisms. The use of equipment and clothing found unduly conducive to the harboring of organisms in crevices or folds should be discouraged.

d. Decontamination

Procedures should be developed for minimizing inadverent transfer of lunar material to the Apollo command module. These might include discarding or appropriate containment of outer garments worn on the lunar surface, careful handling and secure containment of equipment used on the moon but not left there, and especially the containment of whatever samples of lunar material may be collected. These precautions should be built into the protocol for the mission to ensure that astronauts will be practiced in carrying out whatever precautionary manipulations are to be required for them. After completion of the mission no attempts should be made to decontaminate astronaut clothing, equipment, or the capsule itself until the completion of biological studies on returned samples, whereupon the nature and extent of the back contamination hazard will be better appreciated.

e. Pathogenicity to plants and animals

Organisms harmless to man but pathogenic to plants and animals may be indirectly as deleterious to man as those which affect him directly. Even those which are non-pathogenic could produce undesirable changes in terrestrial biota through competition. The Conference believed it important therefore to include among the post-flight tests experiments designed to identify not only human pathogens but also organisms potentially harmful to plant and animal life.

f. Advanced information of lunar and Martian life

Additional information concerning the existence of extraterrestial life will not aid the study of back contamination unless it provides data on the pathogenicity of that life. Considered solely from the standpoint of back contamination, the restoration of biological experiments to the Surveyor lunar missions would not therefore be helpful. Similarly, the Conference did not believe it useful to include life detection equipment in the first manned lunar mission so that the presence of life would be known immediately upon return, rather than only after laboratory analysis of the samples. There were objections to this proposal on other grounds as well: the far greater efficiency and reliability of laboratory analysis; the additional payload weight requirements; and the fact that all precautionary measures against back contamination would already be in force. Finally, negative findings could provide a sense of security which might well be false.

Recommendations

At the close of the Conference, the following recommendations were adopted:

IT IS RECOMMENDED:

1. THAT astronauts returning from lunar or planetary missions be placed in three weeks of strict quarantine upon return to earth; that in the case of lunar missions, the quarantine period should begin from the moment of takeoff from the moon.
2. THAT upon return, spacecraft, astronauts, and all persons who have come in contact with them, be received into an isolation environment, which isolation should be maintained for the duration of the quarantine.
3. THAT spacecraft, suits, and equipment not be decontaminated until biological studies on them have been made.
4. THAT samples be opened as promptly as possible upon return to earth and be examined behind absolute biological barriers, under rigid

bacterial and chemical isolation.

5. THAT immediate steps be taken to formulate detailed operational procedures to permit the handling of samples as recommended in 4. above.
6. THAT in preparing for lunar and planetary missions, a trial run using non-pathogenic organisms be made to develop the most effective methods of minimizing the introduction of foreign matter into the capsule, and to test the extent to which planned equipment may require modification.
7. THAT a study be undertaken to determine techniques necessary to minimize contamination of the mission while on the lunar or planetary surface, with emphasis on the general problem of inadvertent transfer of material. Astronauts should be trained as appropriate in such techniques.
8. THAT post-flight tests include experiments specifically designed to identify organisms harmful to terrestrial plants and animals whether through competition or disease. The protection of the earth's biosphere should be stressed.

Conclusion

In conclusion the Conference stated, "Initially negative information concerning extraterrestrial life will not cause us to change our recommendations, while positive information would easily be reason for more vigorous implementation of those recommendations." The moral, practical responsibility to study and implement protective measures against back contamination is clear. The United States should take leadership in that effort; having recognized that a potential hazard exists, and having the power to incur it, the concomitant responsibilities must be accepted.

The Conference was well aware that it had made only a beginning in the study. The subject is a complex one, not the less so because it is based largely on imponderables. To anticipate and plan for the unknown is exceedingly difficult. To this end, the Conference recommended that persons and organizations who may have carried out relevant research be sought out and their experience utilized. The Conference further believed that a committee should be formed to study the problem in depth; the primary operational responsibility of NASA for the exploration of space should not, however, be unnecessarily impaired.

The necessary imposition of quarantine presents a potentially difficult problem since the returning capsule may land elsewhere than planned, and since public health services, which are responsible for quarantine, have terrestrial not extraterrestrial jurisdiction. The Conference believed it most important, therefore, that a committee be established without delay to prepare detailed quarantine policies appropriate to the various contingencies which may arise.

CONFERENCE

on

POTENTIAL HAZARDS OF BACK CONTAMINATION FROM THE PLANETS

Dr. Allan H. Brown, Chairman

29 - 30 July 1964

Space Science Board
National Academy of Sciences
2101 Constitution Avenue, N. W.
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U. S. Department of Agriculture:	Dr. Herman A. Rodenhiser, Agricultural Research Service
U. S. Army:	Dr. Charles R. Phillips, U. S. Army Biological Laboratories, Ft. Detrick, Maryland
National Institutes of Health:	Dr. Norman B. McCullough, Division of Allergy and Infectious Diseases
U. S. Public Health Service:	Dr. David E. Price, Deputy Surgeon General Dr. Simon P. Abrahams and Mr. Charles Weaver, Radiological Health Mr. E. J. Herringer, Division of Environmental Health Dr. Keith H. Lewis, Robert Taft Sanitary Engineering Center, Cincinnati, Ohio Dr. S. W. Simmons, Communicable Disease Center, Atlanta, Georgia Dr. Joe L. Stockard, Foreign Quarantine
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[*] Appendix A

[**] Appendix B

[***] Appendix C

The possibility of extraterrestrial life entails the chance that returning space missions may bring with them organisms harmful to the earth and its inhabitants. The likelihood of this eventuality, and appropriate methods to deal with it, have been of continuing concern to certain members of the scientific community. The Space Science Board has long felt an obligation to be alert to the problem. In February 1960, a committee of the Board drafted a resolution urging that the matter be given attention (Appendix D); the subject was also considered during the 1962 Iowa City Summer Study. (Appendix E) More recently, on 29-30 July 1964, the Board's Life Sciences Committee held a two-day Conference on the Potential Hazards of Back Contamination from the Planets. Thirty specialists from scientific institutions, government, and universities participated. A summary of the background and discussions of the Conference is given below, followed by its recommendations and conclusions.

Immediacy of the Problem

While much thought and effort have been devoted to the detection of extraterrestrial life and to precautions against contaminating it by terrestrial organisms, much less concerted consideration has geen given the converse problem of back contamination. The complex nature of policy planning, intercurrent research, and the design and construction of suitable equipment requires that considerable lead time be allowed for their effectuation. United States planning for roundtrip missions to the moon and planets has reached an advanced stage; the first manned missions to the moon are planned by the National Aeronautics and Space Administration for 1969, and the first manned missions to Mars will be possible no later than the mid-1980's. Consequently, an evaluation of the likelihood of back contamination, the seriousness of the threat, and of means of protection against it should not be postponed.

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The Conference stressed that, upon return, the samples should be received into an isolation environment, being examined only behind absolute biological barriers, and should remain there for the duration of the quarantine under rigid bacterial and chemical isolation. Owing to the scientific and protective importance of such procedures, immediate steps should be taken to perfect the detailed operational techniques required for sample collection, storage, and examination.

Isolation of the samples on return must not, however, prevent their immediate examination. Data concerning their pathogenicity must be obtained at once. Moreover, since the usefulness of samples for certain tests, such as radio-isotope studies, deteriorates with time, to delay their analysis could impair the scientific value of the mission.

The spacecraft itself should be received into an isolation environment on board the aircraft carrier immediately upon recovery from the sea. The number of persons permitted to come in contact with the capsule - raising it from the ocean, securing it to the deck, assisting the astronauts to get out - should be kept to an absolute minimum and be required to undergo quarantine. The complexity of the operation and the specialized logistic requirements of an isolation environment are such that, in the Conference's view, detailed study of the problem should not be postponed.

c. Prevention of contamination

Although it will not be possible entirely to prevent contamination of the mission if contamination can occur, it should be possible by preventive technique to reduce substantially the number of contaminants. Every contact with the extraterrestrial environment is a potential source of pathogens; therefore the effectiveness with which each contact can be severed before leaving the environment will decrease the contamination.

In collecting samples, astronauts should be trained in clean-and-sterile techniques so as to avoid the spread of contaminants which may be present. Despite plastic shields on hands and feet to be discarded when astronauts re-enter the capsule, some particles from the lunar or planetary surface which have adhered to their clothing or equipment almost certainly will be introduced inadvertently into the capsule. Techniques to minimize this major source of contamination should be developed. The Conference recommended that three areas of research be utilized:

1. Studies already underway in other fields should be examined for their potential relevence.
2. A study specifically designed to expose problems which may arise in space missions should be initiated.
3. A trial run with capsule and astronauts should be carried out using non-pathogenic organisms. The use of equipment and clothing found unduly conducive to the harboring of organisms in crevices or folds should be discouraged.

d. Decontamination

Procedures should be developed for minimizing inadverent transfer of lunar material to the Apollo command module. These might include discarding or appropriate containment of outer garments worn on the lunar surface, careful handling and secure containment of equipment used on the moon but not left there, and especially the containment of whatever samples of lunar material may be collected. These precautions should be built into the protocol for the mission to ensure that astronauts will be practiced in carrying out whatever precautionary manipulations are to be required of them.

After completion of the mission no attempts should be made to decontaminate astronaut clothing, equipment, or the capsule itself until the completion of biological studies on returned samples, whereupon the nature and extent of the back contamination hazard will be better appreciated.

e. Pathogenicity to plants and animals

Organisms harmless to man but pathogenic to plants and animals may be indirectly as deleterious to man as those which affect him directly. Even those which are non-pathogenic could produce undesirable changes in terrestrial biota through competition. The Conference believed it important therefore to include among the post-flight tests experiments designed to identify not only human pathogens but also organisms potentially harmful to plant and animal life.

f. Advanced information of lunar and Martian life

Additional information concerning the existence of extraterrestrial life will not aid the study of back contamination unless it provides data on the pathogenicity of that life. Considered solely from the standpoint of back contamination, the restoration of biological experiments to the Surveyor lunar missions would not therefore be helpful. Similarly, the Conference did not believe it useful to include life detection equipment in the first manned lunar mission so that the presence of life would be known immediately upon return, rather than only after laboratory analysis of the samples. There were objections to this proposal on other grounds as well: the far greater efficiency and reliability of laboratory analysis; the additional payload weight requirements; and the fact that all precautionary measures against back contamination would already be in force. Finally, negative findings could provide a sense of security which might well be false.

Recommendations

At the close of the Conference, the following recommendations were adopted:

IT IS RECOMMENDED:

1. THAT astronauts returning from lunar or planetary missions be placed in three weeks of strict quarantine upon return to earth; that in the case of lunar missions, the quarantine period should begin from the moment of takeoff from the moon.
2. THAT upon return, spacecraft, astronauts, and all persons who have come in contact with them, be received into an isolation environment, which isolation should be maintained for the duration of the quarantine.
3. THAT spacecraft, suits, and equipment not be decontaminated until biological studies on them have been made.
4. THAT samples be opened as promptly as possible upon return to earth and be examined behind absolute biological barriers, under rigid bacterial and chemical isolation.
5. THAT immediate steps be taken to formulate detailed operational procedures to permit the handling of samples as recommended in 4. above.
6. THAT in preparing for lunar and planetary missions, a trial run using non-pathogenic organisms be made to develop the most effective methods of minimizing the introduction of foreign matter into the capsule, and to

test the extent to which planned equipment may require modification.

7. THAT a study be undertaken to determine techniques necessary to minimize contamination of the mission while on the lunar or planetary surface, with emphasis on the general problem of inadvertent transfer of material. Astronauts should be trained as appropriate in such techniques.

8. THAT post-flight tests include experiments specifically designed to identify organisms harmful to terrestrial plants and animals whether through competition or disease. The protection of the earth's biosphere should be stressed.

Conclusion

In conclusion the Conference stated, "Initially negative information concerning extraterrestrial life will not cause us to change our recommendations, while positive information would easily be reason for more vigorous implementation of those recommendations." The moral, practical responsibility to study and implement protective measures against back contamination is clear. The United States should take leadership in that effort; having recognized that a potential hazard exists, and having the power to incur it, the conconitant responsibilities must be accepted.

The Conference was well aware that it had made only a beginning in the study. The subject is a complex one, not the less so because it is based largely on imponderables. To anticipate and plan for the unknown is exceedingly difficult. To this end, the Conference recommended that persons and organizations who may have carried out relevant research be sought out and their experience utilized. The Conference further believed that a committee should be formed to study the problem in depth; the primary operational responsibility of NASA for the exploration of space should not, however, be unnecessarily impaired.

The necessary imposition of quarantine presents a potentially difficult problem since the returning capsule may land elsewhere than planned, and since public health services, which are responsible for quarantine, have terrestrial not extraterrestrial jurisdiction. The Conference believed it most important, therefore, that a committee be established without delay to prepare detailed quarantine policies appropriate to the various contingencies which may arise.

APPENDIX A

A Model of Martian Ecology

Although the environment on Mars differs drastically from that on Earth, the difference is not so great that the terrestrial biologist cannot envisage a group of organisms that would not only survive but flourish under Martian conditions. In attempting to describe the activities that a Martian organism must carry out in order to survive, it should be remembered that Mars, no more than Earth, can be populated by any single organism. Any model of a Martian ecology must describe a community of organisms the members of which compensate for each other's activities. The sum of these activities constitutes a biological cycle of matter. Ever since the opposite net effects of photosynthesis and respiration have been known (1) it has been understood, at least in general terms, that a world wide balance between these two processes must exist. The Earth is therefore a gigantic balanced aquarium in which the various populations live at steady state levels which are limited by the energy flux through the system and modified for any one organism by other members of the same food chain. "Food" is here used in the most general sense and comprises not only organic matter but also all other necessary chemical components of the environment, such as oxygen, nitrogen, carbon dioxide, mineral salts, etc. On Earth the bio-mass is limited by the energy flux as judged by the following figures. Of the 5 x 10^{24} joules/year which reach the upper atmosphere from the sun about 2 x 10^{24} joules reach the surface of the earth (2). Allowing for infrared radiation which is not used in photosynthesis (50%) and absorption and reflection losses (20%), about 6 x 10^{23} joules are available for photosynthesis in forests, on prairies, and on arable land, and in the ocean. Photosynthesis in the field is about 2% efficient, so that 1.2 x 10^{22} joules can be converted per year. The reduction of 1.0 g C as CO_2 to carbohydrate requires 4 x 10^4 joules (this is a minimum figure which ignores the energy requirement of the conversion of carbohydrates to amino acids and protein synthesis in growth). 1.2 x 10^{22} joules limits the annual productivity of the Earth to 3 x 10^{11} tons C, of which 2.5 x 10^{11} can be fixed in the oceans.

The actual productivity of the oceans is estimated at 100-200 g C per year per m^2 (3,4). The area of our oceans, excluding the Arctic Sea and some marginal waters is 3.5 x 10^{14} m^2. The annual fixation is therefore 3.5-7.0 x 10^{10} tons C per year, or 15-30%, at least, of the theoretical maximum. Considering the uncertainty of the figures it appears that on Earth primary productivity, and hence biomass, are directly limited by the energy flux.

On Mars the biomass must be limited by the available water and a different relationship is therefore imposed on the members of the ecological community.

Conditions on Mars

This discussion of Martian ecology is based on the following description of the planetary environment. Mars possesses an atmosphere which at its surface exerts a pressure of 25 ± 15 mb. This atmosphere consists of about 5 mb carbon dioxide with the remainder most likely a mixture of nitrogen and argon. The atmosphere is transparent to visible light and also admits a high level of ultra-violet radiation. There is no evidence for oxygen, the measurements impose an upper limit of 1% on the Martian atmosphere. In the following discussion two alternative assumptions are made: 1) that there is no oxygen, and 2) there is oxygen present to the detectable limit, namely a partial pressure of 0.25 mb.

Surface temperatures reach 30° C. but a diurnal variation of 100° must be expected in many latitudes. The atmosphere contains water vapor to the extent of 20μ atmospheres. Hoarfrost may form during the Martian night, and water is frozen out at the Martian poles. The waxing and waning of the polar caps with the seasons implies an atmospheric water transport. The light areas of Mars are thought to be covered with limonite of an average particle diameter of 100μ and the dark areas may contain a related material (5). In addition the dark areas based on spectroscopic evidence are covered also with a material which is either acetaldehyde or an aldehyde with similar spectroscopic properties (6). To form a stable ecological system a community of living organisms must not only survive in this environment, but the activities of the organisms must tend to maintain this environment.

Primary Productivity

The external energy source to support a community of organisms is the radiant energy of the sun. Two types of mechanisms may exist to convert the radiant energy into chemical energy. There may be a non-biological sequence of reactions, similar to those that occur in experiments which produce organic matter from primitive atmospheres (7) or there may be a biological energy conversion, namely photosynthesis. The incidence of ultra-violet radiation may bring about a reaction between carbon dioxide, hydrogen, and water to form carbon monoxide, methane, and carbohydrates or related compounds. These larger molecules may precipitate on the surface and serve as the primary source of organic material on which Martian organisms could grow. The alternative would be the existence of photosynthetic organisms which assimilate carbon dioxide in the light. Since oxygen is either absent from the Martian atmosphere, or at best present in extremely low concentration, the Martian photosynthesis would resemble terrestrial bacterial, rather than plant, photosynthesis. Green plants and algae on Earth use water as the ultimate electron donor in photosynthesis with the consequent liberation of oxygen, which indeed is thought to be the major source of oxygen in the terrestrial atmosphere. Photosynthetic bacteria use compounds other than water as their electron donors, such compounds include hydrogen, a variety of reduced sulfur compounds, and other substances.

In the absence of direct information it is nevertheless possible to advance arguments for or against the production of organic compounds by non-biological photochemistry based on a consideration of the selective advantage that such a process may or may not have for the remainder of the Martian population. Should organic matter be produced by non-biological photochemistry at a non-limiting rate, so that there is always an excess of organic matter available to heterotrophic organisms, then there might be no selective pressure which would favor the evolution of photosynthetic organisms. On Earth accumulations of non-living organic matter are rapidly consumed by organisms which develop as rapidly as organic matter is formed, but on Mars life is limited by water and therefore organic matter might conceivably accumulate in excess of the biomass. However, water is also one of the raw materials of non-biological photochemical synthesis and the rate of formation of organic matter by this mechanism must therefore be restricted much as life might be restricted. Other disadvantages of non-biological photochemical synthesis might be that only a fraction of the organic matter so produced might be useful to Martian organisms. In other words, the efficiency of energy conversion in the food chain would be low. Under these circumstances selective advantages might favor the formation of photosynthetic organisms which would be the primary producers of organic matter and the converters of radiant energy into chemical energy. However, the activity of such photosynthetic organisms may be supplemented by the occurrence of "extraorganismal photosynthesis," so that the primary food supply would be in part organically synthesized by photosynthetic organisms and in part "manna from heaven."

Respiration

On Earth photosynthetic processes are counterbalanced by respiratory activities in which oxygen is the terminal electron acceptor. Whether even a small part of respiration of Martian organisms is linked to oxygen will depend on whether the Martian atmosphere contains any oxygen at all. Present observations place an upper limit of 0.25 mb on the partial pressure that oxygen contributes to the Martian atmosphere. Although on Earth the partial pressure of oxygen is nearly three orders of magnitude greater, even such a small amount of oxygen as might exist on Mars would be of biological significance as the following calculation will show. At 0.25 mb the concentration of oxygen is $2.5 \times 10^{-4} \div 22.4 = 1.13 \times 10^{-5}$ moles/litre of oxygen in the atmosphere. The solubility of oxygen in water at 0° is 4.89×10^{-2} ml/ml. The concentration of oxygen in water at 0° would therefore be $1.13 \times 10^{-5} \times 4.89 \times 10^{-2} = 5.46 \times 10^{-7}$ moles/litre. This concentration is marginal for terminal oxidative processes of most terrestrial organisms but significant respiratory activity by terrestrial organisms has been reported at lower concentrations. Thus a micrococcus species has been reported to respire at 1^{o} C. under 0.1 mb oxygen as rapidly as under 200 mb oxygen (8), and light emission by luminescent bacteria can be observed at concentrations considerably below 0.1 mb (9). A variety of of intestinal parasites are reported to respire at extremely low partial pressures of oxygen (10) and germination of certain plant seeds has been observed by Siegel (11) at about 1 mb oxygen. Thus if the Martian atmosphere should contain 0.25 mb oxygen, Martian microorganisms may carry out respiratory activities comparable in their net balance to those of terrestrial organisms.

In the absence of any direct evidence for oxygen we must proceed on the assumption that Mars is anaerobic, but it is worthwhile to consider at this moment the biological significance of aerobic respiration. In the oxidation of organic matter with oxygen as a terminal electron acceptor a greater change in free energy takes place than in the use of any other commonly available electron acceptor. Although such thermodynamic considerations bear no necessary relationship to the biological efficiency with which such energy is utilized, it is clear that more energy is available in aerobic respiration and that some organisms at least will take advantage of this possibility. In a competition for organic substrates aerobic respiration provides an organism with a selective advantage since it gains the same amount of energy at the expense of less organic matter. Experiments on the growth of microorganisms (12) show that growth is directly related to the biologically significant energy that is made available in substrate dissimulation, provided that the raw materials for cell synthesis are present. There is then first of all the advantage in numbers or mass bestowed on those organisms that utilize oxygen. Secondly, the availability of more energy and the use of an electron acceptor which readily diffuses through the living tissue makes possible the evolution of larger multicellular structures than is possible in fermentative organisms. It can be stated as a generalization that all multicellular organisms that we know are aerobic. It is the use of oxygen that enables an organism to devote part of its energy to the maintenance of a constant temperature, that is, to the maintenance of a constant activity largely independent of temperature fluctuations in the environment. This means that an organism so endowed can be active in an environment in which some of its competitors are dormant. Undoubtedly all these faculties are the prerequisite for the development of intelligent life, so that the prerequisites for intelligence were developed when photosynthetic organisms first learned to utilize water as electron donor and thereby discharge oxygen into the atmosphere.

In the absence of oxygen Martian respiratory organisms must use other electron acceptors. Terrestrial examples of anaerobic respirations include the reduction of sulfate to sulfide, in which the sulfur atom accepts electrons in terminal respiration, the reduction of nitrate to nitrogen, and the reduction of CO_2 to methane. Thus a number of common psuedomonads and enteric bacteria will grow at the expense of the reaction

$$5\ CH_3COOH + 8\ NO_3^- \longrightarrow 10\ CO_2 + 4\ N_2 + 6\ H_2O + 8\ OH^-$$

Some of the acetic acid is assimilated to make bacterial matter, but the reaction above summarizes the energy metabolism. Sulfate reduction which is largely carried out by Desulfovibrio proceeds according to the reaction

$$2\ CH_3CHOHCOOH + SO_4^{=} \longrightarrow 2\ CH_3COOH + S^{=} + 2\ CO_2 + 2\ H_2O$$

As a final example a reaction in which methane bacteria produce methane

$$2\ CH_3CH_2OH + CO_2 \longrightarrow 2\ CH_3COOH + CH_4$$

All three processes are thermodynamically spontaneous reactions and the change in free energy supports the growth of the microorganisms, although the change in energy is not so great as it would have been if oxygen had been the electron acceptor. Should reactions of this type occur on Mars, that is, should organic matter produced in photo-synthesis be oxidized with the electrons transferred to nitrogen, sulfur, or carbon, then there must be balancing reactions which reoxidize the nitrogen, sulfide, and methane. This recycling of the reduced electron acceptors may be carried out by photosynthetic organisms. Terrestrial photosynthetic microorganisms include the purple sulfur bacteria which reduce carbon dioxide in the light and derive the requisite electrons from sulfide or thiosulfate. Such a metabolism can be ecologically linked to that of the sulfate reducing bacteria as is shown in Figure 1. On Earth such oxidations can also take place at the expense of oxygen. Thus there are microorganisms that will oxidize sulfide or methane and ammonia to sulfate, CO_2 and nitrate. Light has the same significance for photosynthetic organisms that oxygen has for respiratory organisms, in photosynthesis light is used to create an electron donor and an electron acceptor and thus an electron flow is initiated. The electron acceptor is capable of oxidizing compounds the oxidation of which was at one time thought to proceed only with oxygen. It was found by Scher (13) that non-sulfur purple bacteria could photosynthesize with aromatic compounds such as benzoic acid as an electron donor. The oxidation of methane has also been observed (14); it leads to a photosynthesis which probably proceeds as follows:

$$CH_4 + CO_2 \longrightarrow 2\ (CH_2\ O)$$

Ecological Role of Limonite

The presence of limonite on the Martian surface is potentially of great ecological significance. Iron in its oxidized or reduced form may serve as an electron acceptor in respiration or an electron donor in photosynthesis, while limonite, because of its water content, may in addition serve as a water reservoir on Mars. Limonite is a non-crystalline iron ore, containing chiefly goethite or lepidocrocite ($Fe_2O_3.H_2O$) and additional absorbed water (15). Its average composition is $(Fe_2O_3)_2.3H_2O$, but only about two-thirds of the water is water of crystallization. The ferric iron of limonite may be thought to serve as a respiratory substrate for Martian organisms, a respiration in which iron serves as the terminal respiratory electron acceptor. This respiration can be described by

$$2n\ Fe_2O_3 + (CH_2O) \longrightarrow 4n\ FeO + n\ CO_2 + n\ H_2O$$

In the reduction of limonite, that is ferric oxide, to ferrous oxide the bound water would be set free in addition to whatever is formed in the oxidation of organic substrates. Terrestrial organisms are known, at least in crude culture, which can live by the oxidation of organic substrates with ferric hydroxide as the terminal electron acceptor (16). The reoxidation of the ferrous oxide to the ferric form can reasonably be expected to support a photosynthesis which would take the following form

$$4n\ FeO + n\ CO_2 + n\ H_2O \xrightarrow{light} 2n\ Fe_2O_3 + (CH_2O)_n$$

There would therefore exist an ecological coupling between a respiration transferring electrons to ferric iron and a photosynthesis deriving electrons from ferrous iron. The limonite would at the same time serve as a water buffer, in the sense that its reduction to ferrous iron would give up water while the newly formed ferric oxide would gradually take up water to reform limonite. Martian organisms might therefore be thought of as swimming in an ocean of limonite. It is worth noting in this connection that the partial pressure of water in the Martian atmosphere corresponds to that observed above limonite (17).

There is an additional consequence of such an iron cycle. Wherever living organisms are active on Mars there would be present simultaneously both oxidized and reduced iron compounds. In the presence of chelating compounds such a mixture is likely to produce intensely colored complexes of the type of which Prussian blue is an example. Should the dark areas on Mars be the result of biological activity their color may well find its explanation in the formation of such complexes.

Organic Matter on Mars

The absorption spectra obtained by Sinton (18) can be interpreted as resulting from acetaldehyde covering the dark areas of Mars. The dark areas constitute about 40% of the surface of Mars and would have to be covered by one millimeter atmosphere of acetaldehyde to account for the intensity of the absorption bands. Assuming an atmospheric pressure of 25 mb, acetaldehyde would boil on Mars at -49° C. and even at -80° it exerts a vapor pressure of 1 mm mercury. It is therefore difficult to understand why acetaldehyde should be confined to the dark areas. If it indeed vaporizes then, in order to maintain such a high concentration over the dark areas, a complete turnover of the acetaldehyde must take place in 40 minutes. It is instructive to evaluate this turnover rate in terms of the possible Martian biomass. A concentration of 1 mm atmosphere of acetaldehyde over the dark areas means that there are $10^{-4} \div 22.4 = 4.47 \times 10^{-6}$ moles or $44 \times 4.47 \times 10^{-6} = 1.97 \times 10^{-4}$ gms acetaldehyde/cm^2. On Earth the biomass is approximately 10 times the amount of atmospheric water or about 10 gm/cm^2. Assuming a similar relationship for Mars we obtain for 2×10^{-3} gm water/cm^2 a biomass of 2×10^{-2} gm living matter/cm^2. The amount of acetaldehyde turned over in 40 minutes is therefore only 1% of the biomass, a very low rate if one judges by terrestrial microbiological standards.

For example, a cell of E. coli weighs 10^{-12} gm wet or 10^{-13} gm dry weight. In order to synthesize that amount of material the cell requires 10^{-14} moles of ATP which in a glycolytic path are made from 5×10^{-15} moles of glucose or 9×10^{-13} gm of glucose. Adding to this amount simply the weight of material needed to synthesize a new cell it means that E. coli turns over 10^{-12} gm of matter for every new cell. The total turnover of matter is therefore equal to the biomass per generation time which may be as short as 20 minutes or 200 times the rate we have just estimated for Martian metabolism. However, another argument can be made for comparable rates of metabolism of Martian and terrestrial organisms if we assume a biological basis for the seasonal darkening of certain areas on Mars. The wave of darkening on Mars travels at 35 km per day, while spring in the U.S. Middle West advances 40 km per day.

The absorption bands observed by Sinton may be caused by more than one aldehyde, among which glycolaldehyde, glyceraldehyde, and methylglyoxal would be of special biological interest. Assuming for the moment the presence of acetaldehyde alone, the acetaldehyde vapor should undergo photolysis according to the reaction

$$CH_3CHO \longrightarrow CH_4 + CO$$

In analogy with terrestrial microorganisms which oxidize CO the CO might be reoxidized in the following respiratory reaction:

$$CO + Fe_2O_3 \longrightarrow 2\ FeO + CO_2$$

As has been discussed above (Ecological Role of Limonite) the resulting FeO and CO_2 can then be consumed in photosynthesis:

$$4\ FeO + CO_2 + H_2O \longrightarrow (CH_2O) + 2\ Fe_2O_3$$

Methane is the electron donor in another photosynthetic reaction (14):

$$CH_4 + CO_2 \longrightarrow 2\ (CH_2O)$$

The foregoing reactions add up to

$$CH_3CHO + 0.5\ CO_2 + 0.5\ H_2O \longrightarrow 2.5\ (CH_2O)$$

that is, the conversion of acetaldehyde to organic matter of carbohydrate composition, with the consumption of additional water and carbon dioxide by a sequence of reactions which includes photolysis, photosynthesis, and respiration.

The formation of acetaldehyde can be formulated in two ways. Either the photosynthetic reactions above are rewritten so as to indicate the synthesis of acetaldehyde rather than the formation of carbohydrates, or we assume a fermentation of carbohydrates to products which include acetaldehyde. The choice of either hypothesis leads to the same net result. To use glucose as a familiar example, such fermentations might take the form of

$$C_6H_{12}O_6 \longrightarrow 2\ CH_3CHO + 2\ CO_2 + 2\ H_2 \quad \Delta F = -30\ \text{kcal}$$

$$\text{or}\quad C_6H_{12}O_6 \longrightarrow 2\ CH_3CHO + 2\ HCOOH \quad \Delta F = -12\ \text{kcal}$$

On Earth the formation of acetaldehyde is usually followed by its condensation to acetoin so that free acetaldehyde does not accumulate, but in principle there is no reason why acetaldehyde should not be a fermentation product.

Structure, Morphology, and General Physiology of Martian Organisms

The structure of Martian organisms will be dictated by the necessity of withstanding extremes in temperature and the necessity of exploiting those conditions under which the fluid of the internal environment is liquid. Organisms must also compete for water and specialize in its conservation. In addition to the high UV flux they may require the evolution of shielding or other protective devices.

Organisms may maintain the liquid state of their body fluids by several techniques. Pigmented organisms absorb radiation and raise their temperature. The freezing point of their body fluids may also be depressed by the incorporation of solutes. Terrestrial halophilic microorganisms contain internally salt concentrations that approximate that of the external medium (19). Depending on the choice of the salts the freezing point of an aqueous medium may be depressed to

-50^{o}. Alternatively, organic solutes such as glycerol may in part depress the freezing point and in part prevent the formation of crystalline ice which would otherwise disrupt the structures of the organism. Such a mechanism is known to contribute to the protection of moth pupae, such as Cecropia and Luna which survive winters with extreme temperatures (20).

The necessity to conserve water is compatible with the necessity to maintain temperatures above the environment. Thus transpiration in photosynthetic organisms would be kept to a minimum. In the absence of transpiration photosynthetic organisms would not be cooled, but their temperature would be raised by absorbed radiation. Without transpiration pull water could rise only by osmotic and capillary mechanisms, but it is not clear to what extent this restriction limits the height of a plant. Lacking the net flow of water caused by transpiration, Martian plants may evolve a coenocytic structure and carry out translocation by cyclosis.

The mechanism which would prevent transpiration might be a waxy or fatty layer over the organism. Such a layer would be largely impermeable to water but permeable to acetaldehyde, and might in addition serve as a UV shield. Generally waxy or fatty structures would be more important on Mars than carbohydrate structures, if one can judge by terrestrial experience in which carbohydrate storage is more frequently an aerobic process, while fats are stored in the absence of oxygen. Hence plants may not have rigid structural material such as cellulose and lignin on Mars, but replace them with a silica skeleton. Fats are also a more efficient store of hydrogen than are carbohydrates.

For protection against UV radiation Martian organisms may develop three kinds of defenses. Highly absorbent organic material may be incorporated in the cell wall or in a waxy cuticle such as mentioned above. The radiation so absorbed would also serve to raise the temperature of the organism. An absorbent inorganic material, such as the limonite of Martian soil, could be combined with a silica shell to make a rigid iron glass with strong UV absorbing properties. Finally, an organism might be shielded by fluorescent material and the emitted light could support photosynthesis.

The ecological niches which Martian organisms occupy are summarized in Figure 1. The occurrence and significance of many of the individual reactions have been outlined above, only the nitrogen cycle required additional discussion. The immediate source of biologically significant nitrogen is ammonia. This ammonia can be provided either as soluble ammonium compounds or it may arise by reduction of other nitrogen compounds. Many microorganisms are capable of reducing nitrate and nitrite to ammonia, others are able to fix atmospheric nitrogen which is reduced to ammonia. In the respiratory utilization of nitrate the end product is gaseous nitrogen, which then enters the nitrogen cycle by nitrogen fixation. The recycling of ammonia to nitrate is in our experience a strictly aerobic reaction, carried out by the autotrophic nitrifying bacteria which derive their energy by the oxidation of ammonia to oxides of nitrogen. Should the Martian atmosphere be entirely devoid of oxygen the nitrogen metabolism of the Martian organisms may follow either of the two following patterns: 1) There may be no nitrogen cycle in the redox sense, but all biologically significant nitrogen shuttles back and forth between free ammonia or ammonium compounds and organic amines. 2) There is an anaerotic oxidation of ammonia to nitrate, for which one likely candidate would be the utilization of ammonia as an electron donor in bacterial photosynthesis. An alternative would be an autotrophic organism using ammonia as the electron donor and ferric oxide as electron acceptor. No organisms of this type are as yet known on Earth.

Conclusions

Mars may be populated by a community of mircoorganisms and plants which utilize sunlight as the primary energy source and catalyze a cycle of matter on the surface of the planet. Microorganisms may vary from forms which live a few millimeters below the surface in a microclimate which affords some protection from ultraviolet radiation and favors retention of water and organic matter, to shielded organisms which expose themselves on the very surface of the soil. One attractive model for such shielded organisms are the Testacidae, the armoured sarcodina, such as Arcella or Difflugia. The shells of such organisms on Mars may be largely opaque to ultraviolet radiation and their amoeboid character may account for attachment to the substrate or to each other. Such attachment is suggested by the observation that Martian storms whirl up material from the light areas and occasionally deposit them as a visible light spot on a dark area, but the aeolian transport of dark material has not been observed.

If the seasonal darkening of certain Martian regions is indicative of biological activity then one would ascribe a rate of metabolism to Martian organisms which is comparable to that of terrestrial organisms. This is judged from the darkening of the nuclei which takes place in a matter of days and from the rate of advance of the wave of darkening. These rates are compatible with a generation time measured in hours rather than in days or weeks. The largest organisms on Mars may be plants which lack transpiration, which are coenocytic and translocate by cyclosis, and which lack rigid support unless they elaborate a silicious skeleton. It has been suggested that the disappearance of a light area which has been formed in a dark region as the result of a "sandstorm," is the sliding off of soil particles from the leaves or limbs of such plants. An alternative is that the soil microorganisms multiply and overgrow such soil deposits. Soil from light colored areas carried by the wind into dark regions may be a fertilizer and stimulate growth of organisms by supplying fresh limonite with additional water or trace nutrients.

For the Martian organisms spring begins when the rise in average temperature makes water available for photosynthesis. The occurrence of photosynthesis and the absorption of light by multiplying photosynthetic organisms contributes to a further temperature rise in the microclimate. The heterotrophic part of the population follows suit and respires accumulated organic matter with the reduction of iron compounds. At this stage the soil darkens as complexes of chelating agents with ferrous and ferric irons precipitate. In the fall the falling temperature inactivates heterotrophic organisms first, while the photosynthetic organisms, owing to their ability to warm themselves with absorbed light, remain active longer. Consequently iron compounds continue to be oxidized, the dark complexes dissociate, and the ground turns lighter. As winter descends the ferric oxide slowly absorbs water and returns to limonite, and thus stores water for the following spring.

Consequences

The speculative outline of Martian ecology points out those possibilities for which "life detection" experiments should be prepared. Instrument landings should take place in a dark area and sampling should take place after the wave of darkening has passed. If more than one landing is feasible then light and dark areas should be compared. Attempts to cultivate microorganisms should make use of sampling devices which can gather particles larger than 100μ and culture media should accommodate the major ecological niches with allowance for halophilic organisms.

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ESS:7/21/64

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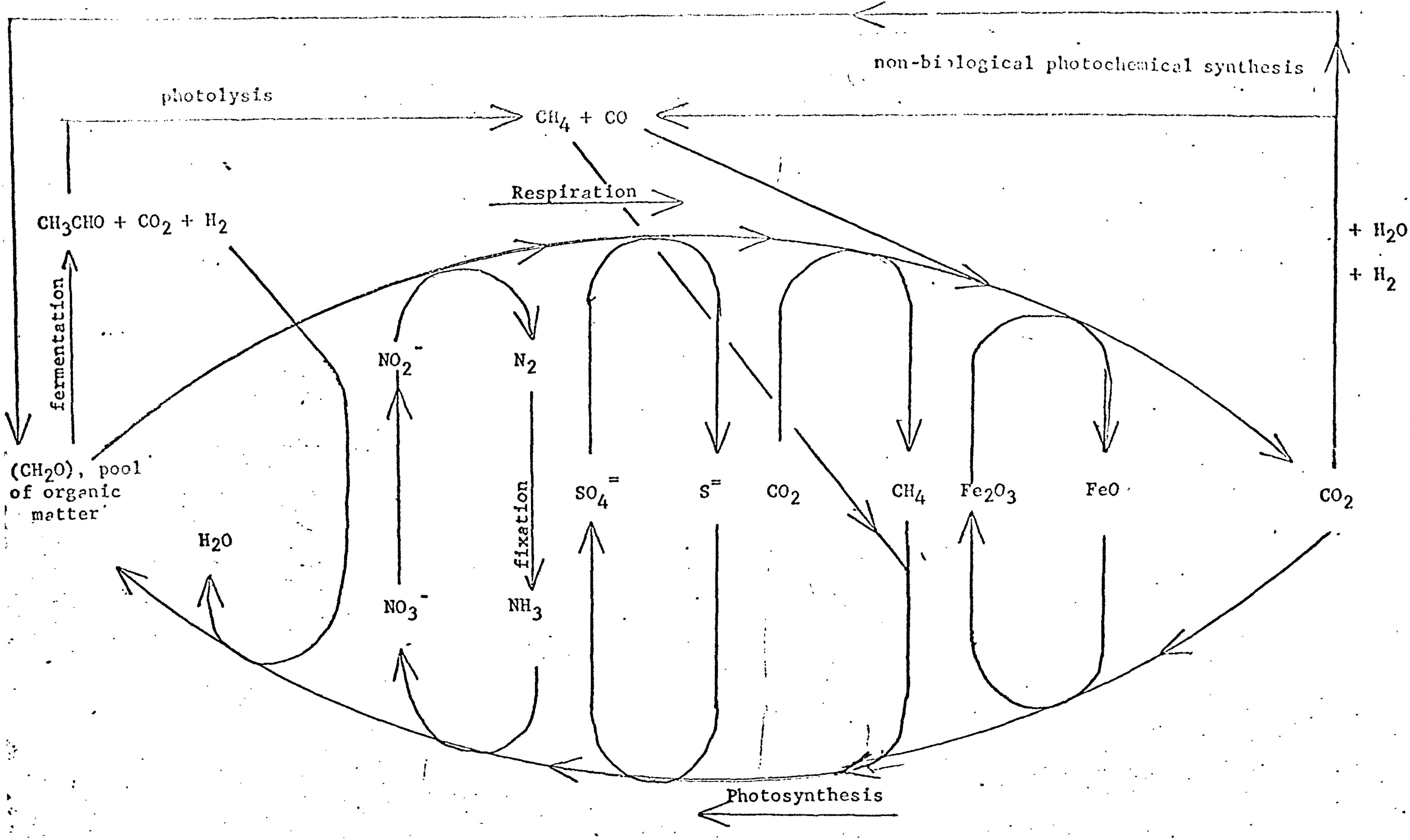

Figure 1. Cycles of matter on Mars.

APPENDIX B

Plans for Sample Collection and Return[*]

by

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The Bioscience Panel of the Apollo Science Team has been organized recently by the Office of Space Science and Applications, National Aeronautics and Space Administration, for making recommendations to maximize the biological and organic-geochemical information that could be attained from the early Apollo landings. The Panel is one of several other teams, whose task is to advise NASA in scientific matters related to the Apollo project as well as to actively help in the analysis of the first samples of material brought back from the Moon. The Panel consists of the following members:

Dr. Melvin Calvin, Chairman, University of California, Berkeley
Dr. K. Bieman, Massachusetts Institute of Technology
Dr. G. Anderson, University of Minnesota
Dr. L. Carlson, University of Kentucky
Dr. R. Lemmon, University of California, Berkeley
Dr. A. Haagen-Smit, Cal. Tech.
Dr. C. Phillips, Ft. Detrick, Maryland
Dr. A. Tousimis, George Washington University

This Panel was asked to formulate a program of investigations, based on the recommendations of the Iowa Summer Study, in close cooperation with the other Apollo scientific panels. Once the program has been defined, NASA will invite proposals from the Bioscience Panel and from a large segment of the scientific community for the purpose of assuring that the Apollo science program is well balanced, sound and as complete as possible, and that all potential investigators have been given an opportunity to propose experiments. The pertinent proposals will then be reviewed by the Bioscience Subcommittee of the NASA Space Science Steering Committee, and, after approval, referred to the Manned Space Flight Experiments Board for final acceptance as part of the mission.

The Biosciences Panel of the Apollo Sciences Team has transmitted

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[*] Report on the work of the Bioscience Panel for Apollo to the Life Sciences Committee of the National Academy of Sciences, 29 July 1964

Arrangements for multiple-use of the lunar samples is highly desirable. It should be quite feasible for the organic chemists to do their extractions and then give the material to other scientists, for whose work the simple extractions would not interfere.

Like the biologists, the organic chemists would prefer sub-surface samples. Samples taken from the lunar surface, even from sun-shaded locales, will be of far less interest. The material below the lunar surface should be older and more protected from cosmic ray effects. All samples should be packaged separately and accompanied by a description of the location, depth, and its relation to the position of the LEM.

Sampling Devices

The best way to collect samples may not be known until the "Surveyor" missions have provided us with a good knowledge of the character of the lunar surface where Apollo landing(s) will be made. However, it seems advisable at this time to make tentative plans for sample taking from a model surface that is (a) thick dust or finely divided material and (b) solid rock. In the case of (a), the device shown by Dr. Shoemaker of the Geology Panel at the Houston Symposium should be suitable to enable the astronauts to reach down and take samples from as deep a position as possible in the "dust" layer. However, this device needs alteration to permit the gathering of small as well as large samples. The sample scoop must be completely sterile and completely free of organic compounds. If case (b) holds and the LEM lands on solid rock, some kind of a drill or "coring" device will be necessary. It is the understanding of the Panel that NASA has such a device under development, but that it is too heavy to go on the first Apollo manned lunar landing. If that is true, and if the first landing will be on solid rock, it is recommended that the astronauts be provided with some sort of pick-and-shovel combination which may enable them to chip off a few inches of the upper surface and bring back at least a few chunks of the underlying material. Again, such a device must be sterile.

Sample Containers

This is a subject that is of great interest to all the scientific panels on which considerable agreement was reached at the Houston meeting. In common with the other panels the Biosciences Panel strongly recommends that the sample packages be made of metal (aluminum appears to be a very good choice), that they be gas-tight, that their sealing be accomplished by the simple repressurization of the LEM, and that the aluminum containers be equipped with indiumwire or gold-wire seals. Such seals are in use in the laboratories of A. Tousimis (George Washington University) and J. R. Cuthill (National Bureau of Standards). Since the sample storage compartment in the LEM will be rectangular, the containers should be of the same shape. After the astronaut had placed a sample in the "box," the top would then be laid on the indium strip. On return to the LEM and repressurization of the module, the aluminum-indium would form a tight seal. Of course, the containers must be kept clean and sterile.

It would be of considerable value if, after the aluminum containers were placed in the LEM's storage compartment, the compartment could be pressurized up to 1 atmosphere with a cylinder of carefully-purified nitrogen. In this way no oxygen, water, bacteria, etc. could reach the samples even if one or more sample containers developed a leak. A 2-cubic foot sample storage compartment could be pressurized to 1 atmosphere with a very small amount of gas. One of the samples should be placed in a sealed metal container that will permit mass spectrometric examination of any volatile material that might diffuse out during transit. Dr. P. Gast of the Geochemistry Panel is in charge of the arrangements for the initial mass spectrometric examination in Houston, and Dr. Biemann will collaborate with him in a search for volatile compounds. The sample container whose content is to be analyzed should be opened directly into the mass spectrometer while the spectrum is continuously scanned. For this, some way of connecting the sample-container and spectrometer has to be designed. The construction of such a device should present no engineering problem.

Seismology Charges and Retrorocket Fuel

Some of the planned seismology experiments will require the setting off of small explosive charges on the moon. In order to prevent destruction of possible organic compounds, the charges should be set off only after the samples for the organic chemists have been collected and safely stored in the LEM.

Much more serious is the problem of the LEM's retrorocket fuel. On its lunar landing, the LEM's motors will burn about 4,000 lbs. of a N_2O_4-hydrazine-unsymmetrical dimethylhydrazine mixture. For the organic chemists and their search for traces of lunar organic compounds, this is a serious situation. It emphasizes the necessity of sub-surface samples and samples taken as far away from the landing site as possible. If, on landing, the LEM approaches the lunar surface tangentially, the samples should be collected away from the LEM in the direction opposite to the approach path.

Regarding the retrorocket fuel, it is strongly recommended by the Panel that a study be made both of the tface organic impurities in the fuel and of the combustion products formed when the N_2O_4-dimethylhydrazine mixture is burned in a vacuum. It would be particularly valuable if such studies could be made in the presence of the kinds of material expected on the lunar surface. The organic chemists need to know not only the obvious, volatile combustion products (CO_2, CO, H_2O, N_2, H_2, NO, etc.) but what higher molecular weight organic compounds are present or formed, including those produced in minute quantities. Gas chromatography should be used in the search for the organic products of the dimethylhydrazine oxidation, and a sample of both the N_2O_4 and the dimethylyhydrazine used for the LEM should be saved for comparative studies.

Perdeutero dimethylhydrazine (with all hydrogen atoms replaced by deuterium) was proposed by the Panel as retrorocket fuel for a later Apollo manned landing if (a) no further isotopic ratios (H/D ratios, at least) were to be determined and (b) the organic analyses failed to settle clearly whether a particular compound was of lunar origin or came from retrorocket fuel burning.

Outgassing of the Space Suits

Another matter of concern to the Panel is the possible outgassing of the astronauts' suits during the sample-collecting trips from the LEM. This might lead to troublesome chemical contamination of the samples. It is the Panel's recommendation that a thorough study be made of the volatile compounds that escape from the space-suit materials under the lunar temperature and pressure conditions. It is particularly important that gas chromatographic and mass spectrophotometric records be made of such volatile compounds. Furthermore, such records should be obtained in consultation with, or under the supervision of, the scientists who will be examining the returned lunar samples for volatile organic compounds.

If studies of the outgassing of the suits indicated severe organic-compound contamination, it is suggested that the possibility would be considered of substituting material of extremely low vapor pressure (metals, metal bellows) in the construction of the space suits. However, the technical problems involved may be quite insurmountable.

Astronaut Training

The astronauts are already receiving extensive training in geology and other earth sciences. This should be extended to include microbiological training as well. This training could be given by the microbiologist who is joining the MSC Staff, Dr. Elmo Dooley. The instruction should emphasize methods of collecting and handling samples under aseptic conditions, and should demonstrate how easily sterile material can become contaminated with a person's own microbiological flora. The astronauts should be shown the common laboratory demonstration of bacterial transfer such as that effected by placing one's finger on, or coughing over, an open petri dish. They should also practice handling and transferring sterile material, and demonstrate that they can do this without contamination.

Final sections of the report outlines the Panel's recommendations for minimizing back contamination to the Earth.

The Returning Command Module and Equipment

The exterior of the Command Model (CM) ought to be essentially free of organisms and should require no treatment. However, all the equipment and sample packages -- in fact, everything that comes out of the CM -- should be considered as possible carriers of lunar pathogens. The Panel feels that it would be advisable at least to wipe off, perhaps with dilute hypochlorite solution, all the outside surfaces of objects as they are being removed from the CM. After all objects of value are removed, the interior of the module could be decontaminated with one of the standard vapor-phase bactericides.

Scientific and General Equipment

The scientific instruments and general equipment used on the lunar surface will be stored on the LEM in equipment bays. All such equipment should be biologically decontaminated when the bays are finally closed before the launching from the Earth. It is suggested that ethylene oxide be used for this purpose. This compound is an effective disinfectant and is the least liable either to cause damage to any instruments or to leave any residue that would be objectionable in the search for organic compounds on the moon.

Consideration of Quarantine

The most likely source of lunar pathogens, if indeed any exist, would be the astronauts themselves. Lunar organisms, even if not inherently pathogenic, could, acting in conjunction with terrestrial organisms in the nose and throat of an astronaut, produce disease. Since such a symbiotic relationship would depend on the organisms normally found in the respiratory flora of different persons, one could equally conceive that, while the astronauts themselves might not possess the proper combination for activation of lunar organisms, they could in theory transmit such organisms to other persons whose nasal flora did contain suitable symbiotics. Under such circumstances, one would have to consider that any illness occurring within the astronauts within a few weeks after return -- or among persons in contact with the astronauts -- would have to be thought of as potentially significant and therefore subject to strict measures.

There is also the question of scientists whose studies may necessitate some direct contact with the lunar samples soon after they are brought to Houston. It is the Panel's hope and expectation that no unprotected contact will be necessary. The scientific work that needs to be done quickly should be done behind biological barriers. Reports on the specifications, commercial availability, and constructional details of such barriers have already been sent to Dr. Elliott Harris at the MSC. The other scientific panels have already indicated that the studies that need to be done immediately on arrival of the lunar samples at Houston (e.g., x-ray spectroscopy of the radioactive isotopes, mass spectrometry of volatile material) can indeed be done behind the biological barriers. However, if it develops that the bacteriological cabinets cannot be used, a scientist directly exposed to the lunar material may have to be temporarily quarantined.

The whole question of the possible back contamination is a public health matter, and, for that reason, the Biosciences Panel feels that further expert advice and opinion should be sought. It is the feeling of the Panel that it is its responsibility to state the problem, but not necessarily to make recommendations as to how it can be solved. The Panel further hopes that the Life Sciences Committee of the National Academy of Sciences at its conference on this subject in Washington on July 29-30 will be able to make firm recommendations on the public health aspects in order to prevent a possible back contamination of the earth.

Summary of Sampling Recommendations

It is perhaps worthwhile to summarize here the Biosciences Panel's recommendations regarding sample types, collection, packaging, and transport. In response to the suggestion made by Dr. Verne C. Fryklund, Program Manager for the Apollo Science Program, the recommendations are classified as ideal (I), acceptable (A), and minimum (M).

1. Number and amounts of samples:

(I) Many 1-gram samples of finely divided material collected from different locations (all from sub-surface and permanently shaded spots) plus several sub-surface 500 g-1 kg. samples. (A) Several 1-gram samples and one or two larger samples, collected as above. (M) Anything in any form the astronauts can bring back.

2. Sample collection:

(I and A) Sample material should be collected only with instruments that are sterile and completely free of detectable organic compounds. The locale from where the sample was taken must be recorded on the container. (M) Samples picked up in any fashion the astronauts can devise.

3. Sample containers:

(I) Hermetically-sealed, metal, clean-and-sterile containers; containers placed in inert gas-pressurized storage compartment on the LEM. (A) Samples placed in individual, clean, and sterile plastic containers (preferably Teflon). (M) Samples placed in anything the astronauts can find available.

4. Sample transport:

(I and A) The samples should be kept cool (preferably not above

35° C.) after collections. (M) Anything the astronauts bring back, regardless of what it is subjected to on the return trip, will be scientifically valuable.

APPENDIX C

National Aeronautics and Space Administration Manned Planetary Studies

by

Dr. Franklin P. Dixon
Director, Manned Planetary Mission Studies
NASA Headquarters

Study activities have been underway on Manned Planetary Missions within the National Aeronautics and Space Administration since 1962, when it became evident that a wide variety of capabilities would be required beyond the Apollo program to accomplish either Mars Landing or Venus Orbital Missions. These studies were performed at various government centers and under contract by industry groups starting in May, 1962. The studies have been funded at a moderate level to date, and they have been used to determine the feasibility of various techniques leading to manned planetary travel with Mars and Venus as the initial targets.

The first chart on the Mars Landing Mission (Chart 1) indicates the projected study and development phases consistent with present NASA program commitments and the projected development of technological capabilities. While Manned Planetary Missions are not within an approved NASA development program, the need for study and logical planning is evidenced by the magnitude of the decisions to be made and the 10 to 14 year schedule that is presently envisioned from program go-ahead to successful accomplishment of the first Manned Mars Landing, for example. NASA is presently in the early study phase, which will continue for another two to three years before Project Definition is initiated. Perhaps two years later, but probably in early 1970 we should be able to support a meaningful development program with longer lead-time subsystem efforts started in mid-1969. Such a program should provide adequate mission success probability by the 1980-85 period. There are strong performance arguments for a schedule to meet the 1982 Mars opportunity, presuming our previous trajectory analyses are not altered by techniques for further reducing total propulsion energy requirements.

In the framework of a planetary program schedule, such as this, we must examine a great variety of missions, techniques, subsystems, and other influencing parameters in order to provide NASA management with a sound base for future program choices. Chart 2 on "Most Promising Missions" indicates the missions that best represent early capabilities. Note that we fly by and orbit Venus, we land, orbit and fly by Mars in this matrix. The earliest mission, and easiest from a propulsion viewpoint, is a simply flyby. The flyby can be justified as a building block for capability to perform the ultimate goal of manned landing on Mars and as a technique for gathering astronomical and astrophysical data for 400 to 600 days. Data on the target planet(s) can be gathered from thousands of kilometers away through periapse passage nearest the planet to thousands of kilometers away. The scientists and the crew can sift data, adjust instruments, send atmospheric probes into the planetary atmosphere and transmit results to Earth so that data can be available and experimentation iterated in a very efficient manner.

Capture missions could follow with improved reconnaissance and scientific observations on the target planet. This is probably even more of interest as a final goal for Venus, if we are to believe the present evidence on its hostile environment. Only the future will tell us whether landing on Venus will be desirable.

At the present time Mars offers the best promise of our solar system bodies for an exobiology success. The initial exercises will be with unmanned probes placing experimental laboratories, such as an Automated Biological Laboratory, on the surface of Mars. These early attempts must be followed by a manned biological laboratory for an adequate study return. The last mission mode depicts a Mars landing with a Venus flyby on the return or outbound leg. This particular technique offers a useful way to smooth out the energy requirements for successive opportunities and allows scientific examination of Venus at only slight increase in total trip time. A later chart shows the profile and some data on this mission mode.

For our discussions of manned planetary missions the trip times are important. Two basic mission profiles exist, the opposition class mission, or fast mission, and the conjunction class, or low energy mission. Chart 3 shows the relative positions of the Sun, Earth and Mars for opposition and conjunction. The ellipticity of the Mars orbit about the Sun is also indicated resulting in a variation in energy for each opposition as the relative distance from Earth to Mars varies. The nearest Mars comes is about 34 million miles. For conjunction conditions when Mars is opposite the Earth on the other side of the Sun it is about 250 million miles.

Chart 4 shows three possible mission profiles. The conjunction mission which is about 920 days in length with a stay time near Mars of 480 days is the longest. The Venus swingby on the return leg is somewhat shorter and if it were performed during the 1975 opposition, it would be 490 days in length with a stay time at Mars of 10 days. The direct opposition class mission is somewhat shorter, lasting 430 days, but has an arrival velocity back at Earth of 66,000 feet per second providing a difficult constraint on the entry vehicle for Earth return. One feature that all of the Manned Mars Landing Mission Modules have in common is the long period of time spent on the return phase from Mars to the Earth. This time is on the order of 200 days or more for all promising missions and represents an inherent quarantine period during which any unusual effects of exposure to the Martian environment should have ample time to germinate. This quarantine period plus adequate use of isolation and decontamination techniques, should serve to allay fears of possible back-contamination of the Earth.

During 1963 a series of studies were performed under NASA contract to design the necessary mission modules for a Mars Landing Mission. The spacecraft for the mission is shown in Chart 5 in the form of the Mars Landing Mission Aerobraking Spacecraft. This mother spacecraft or Mars Mission Module (MMM) contains the Mars Excursion Module (MEM) and the Earth Re-entry Module (ERM). It has a capability to provide environment protection throughout the trip and provides artificial gravity of approximately 0.4 times the surface gravity on Earth during interplanetary travel.

After injection into interplanetary transfer which will require a nuclear rocket or large chemical propulsion system, the Mars Mission Module is capable of sustaining a crew of six for the 400 to 500 day mission. It uses the atmosphere of Mars to reduce its arrival velocity and establish orbit. However, should aerobraking prove impractical based on improved data relative to the Mars atmosphere, the orbit could be established by propulsion using chemical rockets or perhaps even nuclear rocket engines. Once in orbit atmospheric probes will be dropped and detailed reconnaissance will be performed along with scientific observations to arrive at the preferred landing site for the Mars Excursion Module. Half the crew will enter the MEM. The three astronauts will then separate from the mother spacecraft and the MEM will enter the Martian atmosphere.

Chart 6 is the Mars Excursion Module inboard profile with its laboratory quarters in the base of an aerodynamic lifting body which flys in the Mars atmosphere and is then decelerated by a parachute and variable thrust retro-rocket to a controlled landing at the chosen site.

A period of 10 to 40 days surface operations can be supported by the MEM with two of the three astronauts performing investigations and experiments outside while the third crew member assembles data and performs various communication and housekeeping functions in the MEM. After sufficient investigations are completed and the 800 pounds of data and samples have been accumulated to fill the payload of the ascent stage, the three astronauts will blast off into an intermediate orbit for later rendezvous with the MEM. The crew will then transfer samples from the MEM and they will be stored in a 300-pound cassette in the Earth Re-entry Module. The MEM will be discarded and the MMM will fire its rockets for return to Earth. The MEM design provides a modified 20 degree half-cone lifting body vehicle that is 36 feet long and 22 feet wide and is capable of performing its mission in a Martian atmosphere with surface pressure as low as 11 millibars, which is thought to be the minimum surface pressure based on recent spectroscopic data.

Chart 7 shows the Earth Re-entry Module that is used for direct high-speed entry at velocities up to 65,000 feet per second and is capable of returning the six man crew and its precious scientific samples to the Earth's surface. It is capable of some maneuvering to help attain a suitable landing site and it should be again emphasized that the armored cassette is capable of surviving a catastropic failure on entry into the Earth's atmosphere to avoid atmospheric contamination by the Mars samples.

Chart 8 indicates the total weight in Earth orbit which is required to perform the Mars Landing Mission. A spacecraft will have a mass corresponding to 1.51 million pounds with nuclear injection propulsion and 3.07 million pounds, if a nuclear stage should not be practical and high energy chemical rockets are employed. It is anticipated that Earth orbit assembly or refueling will probably be required if chemical rockets are employed even with a Post Saturn launch vehicle that could lift one or two million pounds into Earth orbit.

Probably Earth orbital operations will be required even with nuclear rockets and it is then evident that we will have to develop this capability along with a better understanding of human factors for extended space operations before such a mission can be accomplished.

The whole purpose of a Mars Landing Mission is to gather experimental data. The scientific mission objectives are indicated in Chart 9 in a basic way which will provide an understanding of the planetary environment, its internal structure and composition, origin and significance of surface features, possibly some history associated with it, and answer questions as to present or prior existence of life forms. Some of the other aspects are also indicated, but it should be emphasized that the gathering of this data will serve both scientific and the technical communities in providing more information to answer basic questions and to be applied to maximize the chances of success in exploting the capabilities of interplanetary trips to Mars.

Chart 10 shows an artist's concept of the Mars Excursion Module Surface Operations. The MEM is shown with its airlock extended from its base and two of the three astronauts are active outside the vehicle. The parabolic antenna is used for direct communications to the Earth and the portable meteorological station behind the second astronaut gathers continuous data on the Mars environment. The astronauts wear protective plastic shields over their hands and feet which will be discarded before entering the MEM. It may be necessary to have a complete suit similar to those used by decontamination crews in order to maximize the necessary protection. As you can see, some thought has been given to the back-contamination problem. There is much to be done in exploring the possibilities for minimizing potential difficulties. This area of interest will play a major role in the final system design for a Mars Landing Mission, along with efforts to reduce the probability of contamination of Mars surface by the manned environment, which is necessary for such a mission.

In the process of performing surface operations a tentative priority of experimental data collection has been assigned. This is indicated in Chart 11. Although Item 3, "The Biological Evaluation of Life Forms," is the prime experimental objective, it should be noted that the evaluation of local hazards prior to egress is the first and most important activity in order to insure the capability for performing the basic scientific goal. An extensive search for pathogenic life forms and unanticipated effects must be performed before man becomes exposed to the new environment. Test animals which have been carried to the Mars surface will be exposed to the Martian environment before exiting and adequate time allowed to assess the effects of this exposure.

Automatic sampling techniques with micro-inspection will also be used to reduce the probability of unforeseen problems and to insure adequate protection from pathogens. Details on radiation will also be gathered, as well as the meteorological and topological features as indicated in the chart. The rest of the data are sufficiently explained except for the sampling of the moons of Mars: Deimos and Phobos. Although this will probably be accomplished from the MMM with unmanned probes, it is of sufficient interest to be indicated as a goal of manned landing missions.

Charts 12, 13, 14 and 15 go into some detail on the experiments program. The meteorological requirements are first and Chart 12 indicates the experimental data which will be gathered throughout the entire stay. Sounding rockets or balloons will be used as well as the surface instruments for gathering this data. Next is the "Biology Study Program," Chart 13, showing the various branches which might be made in the process of looking for life forms. The ability to alter the course of investigations and to delve more deeply into interesting phenomena justifies the presence of man in the manned landing program. If no visible evidence of life is found, microscopic examination will be pursued, pathogens must be identified and their effects deduced for better understanding of biological evidence and as an input to future mission decisions. The importance of this effort to the world of science and all mankind cannot be overemphasized.

The next area of interest is the "Geological-Geophysical Experimental Data Requirements," (Chart 14) Current plans indicate spacecraft subsystems, high speed re-entry, advanced communications, auxiliary power, etc. Again, it should be emphasized that the capabilities developed in Gemini and Apollo programs are essential precursors to planetary mission activities along with the unmanned probes and Earth orbital operations in support of the extended planetary missions.

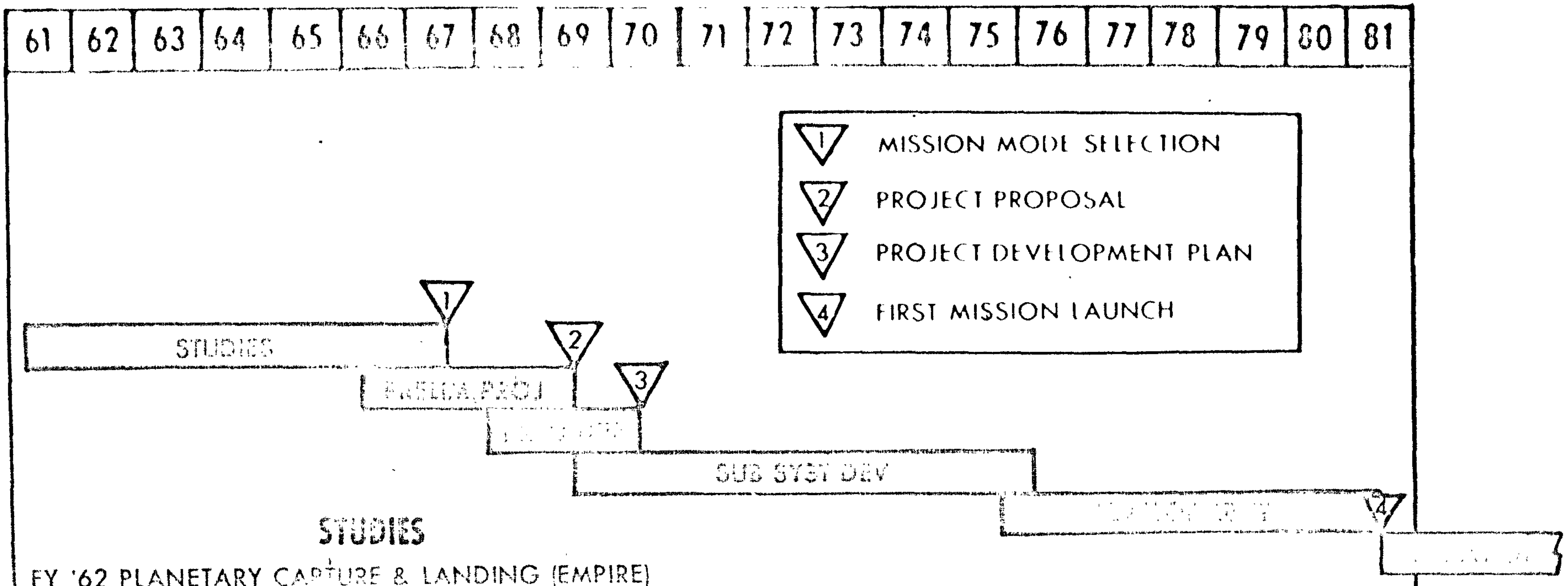
Chart 19 indicates some of these interrelations and represents one of several planning schedules under consideration within NASA for manned space flight missions. This particular schedule shows the lunar, the near Earth orbits, and the near planet missions which might be included in the next two decades. Development of this capability leads to a Mars landing during the 1982 opportunity followed by a Venus orbital mission in 1984-86. The next five years are taken up with the Gemini and Apollo programs and with studies for the planetary missions as indicated in Chart 19. This schedule indicates a sustained effort in lunar exploration, extension of the Apollo vehicle capabilities for Earth orbital activities and development of an orbital research laboratory with a one to three year lifetime along with an adequate planetary mission planning program. This schedule provides essential ingredients for development of the nation's space effort and all elements support the attainment of scientific objectives and serve NASA's responsibility in establishing and maintaining preeminence in space for our national capabilities. The ultimate objective of manned landings on Mars is a logical goal which will be supported by the earlier extensions of our present programs.

In keeping with our basic objectives for today's discussion, I would like to state that NASA's studies have considered the problems of contamination and to reiterate that contamination of the nearby planets, as well as back-contamination, will receive major attention in future manned mission developments. If one failed to recognize the problem of contamination it could be a serious mistake, since this problem should be carefully weighed for effect on mission accomplishments and possible post mission consequences. There is hope in the fact that the quickest return trip from Mars is 150 days using more propulsion than appears feasible from our earlier studies. The more probable time of 200 days would certainly serve as a period of incubation, allowing pathogens which might be present to develop and manifest their effects before Earth return.

In view of these thoughts on manned missions to Mars, it would appear that undue concern precluding aggressive use of our space technology would not be justified, but the possibility of back-contamination will remain an integral part of our future developments. The data from our unmanned probes must be analyzed to provide as much insight as can be gathered at the earliest time. This approach will insure that capabilities required to place scientists on Mars in support of detailed biological and aerological experimentation will be available at the earliest reasonable date.

MARS LANDING MISSION

CALENDAR YEARS

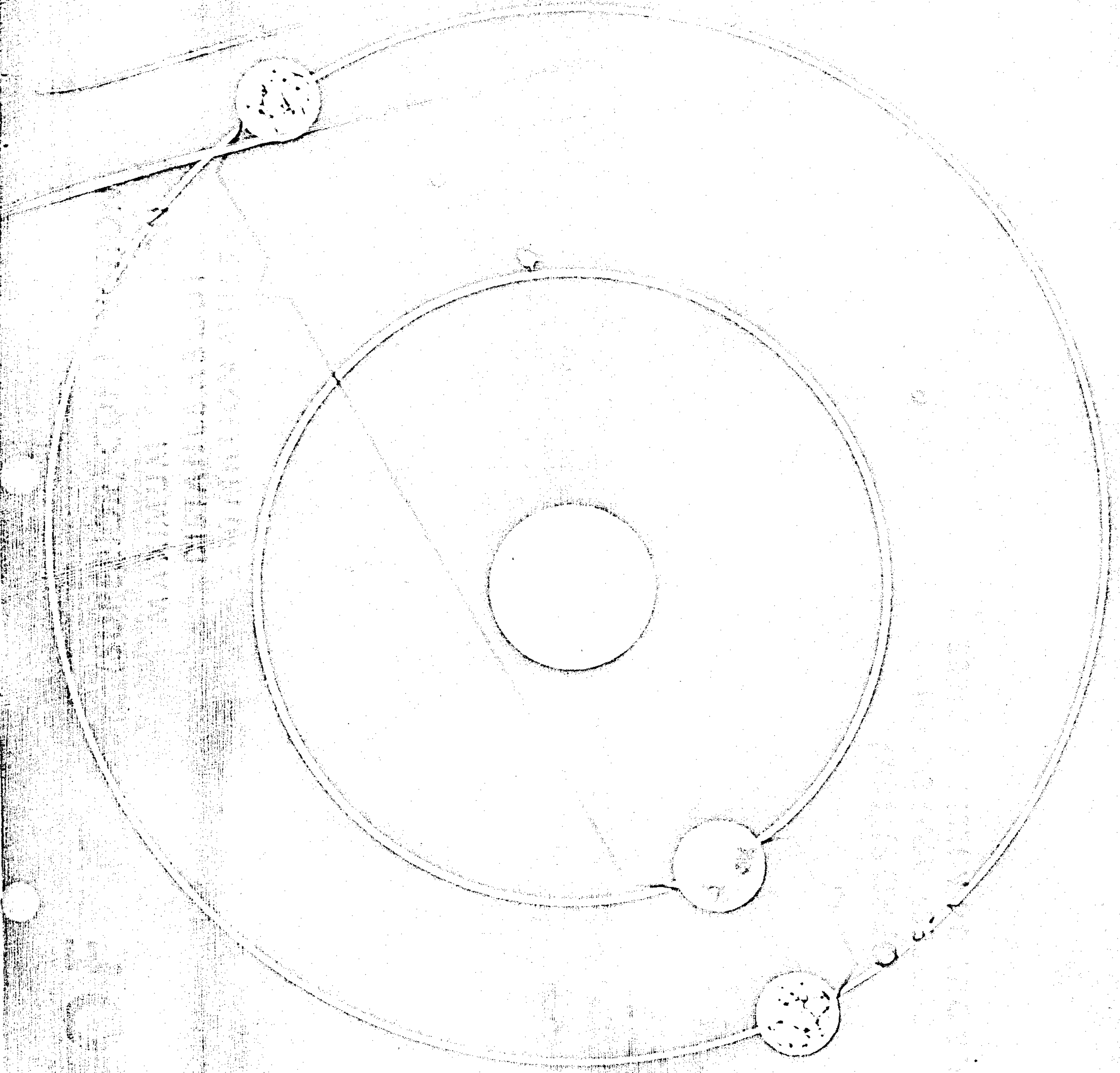


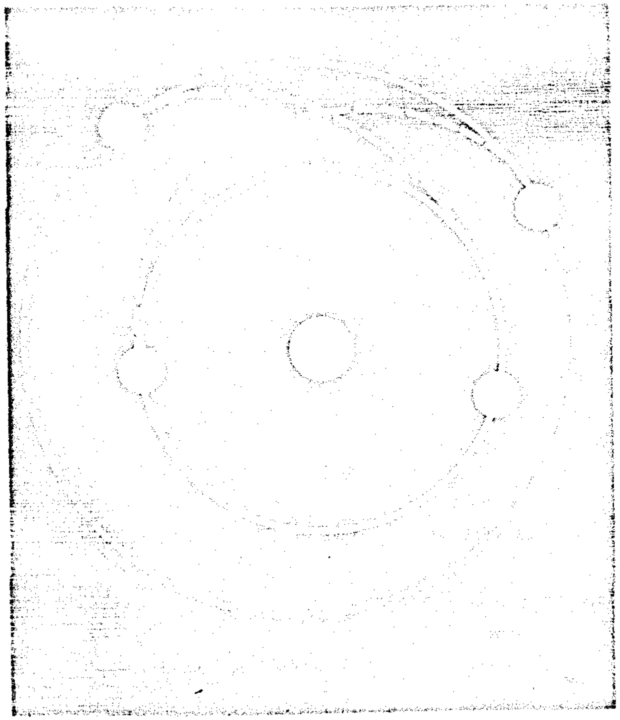
STUDIES

FY '62 PLANETARY CAPTURE & LANDING (EMPIRE)
FY '63 PLANETARY CAPTURE & LANDING, UNFAVORABLE YEARS (2)
MARS LANDING MISSION VEHICLE SYSTEMS (MMM, MEM, ERM) - (3)
FY '64 MARS & VENUS EXPLORATION
MARS SURFACE OPERATIONS
CONJUNCTION CLASS MISSIONS
FY '65 NUCLEAR ELECTRIC MARS & VENUS MISSIONS
CONCEPTUAL DESIGN OF COMMON SPACECRAFT
SURFACE OPERATIONS

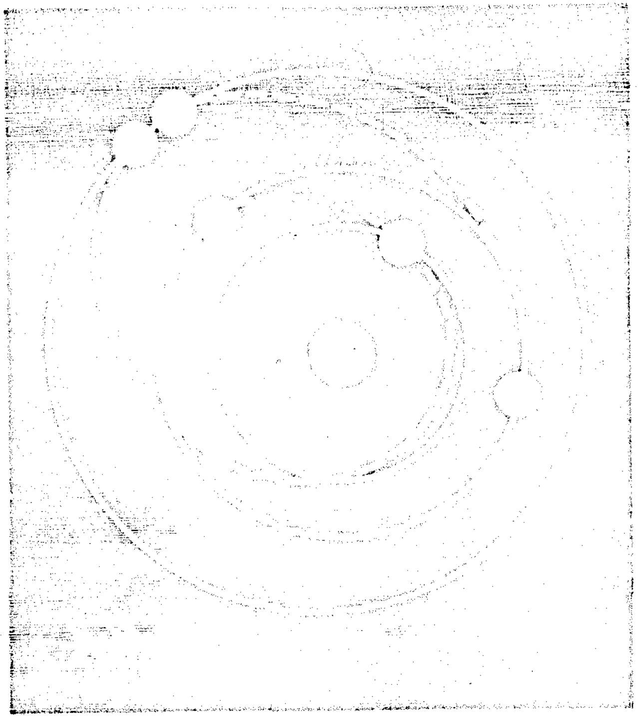
MOST PROMISING MISSIONS

	MARS	VENUS
FLYBY	♂ ♂ ♂	♀ ♀ ♀ ♀
ORBITING	♂	♀
LANDING	♂	?
FLYBY — LANDING	♂	♀

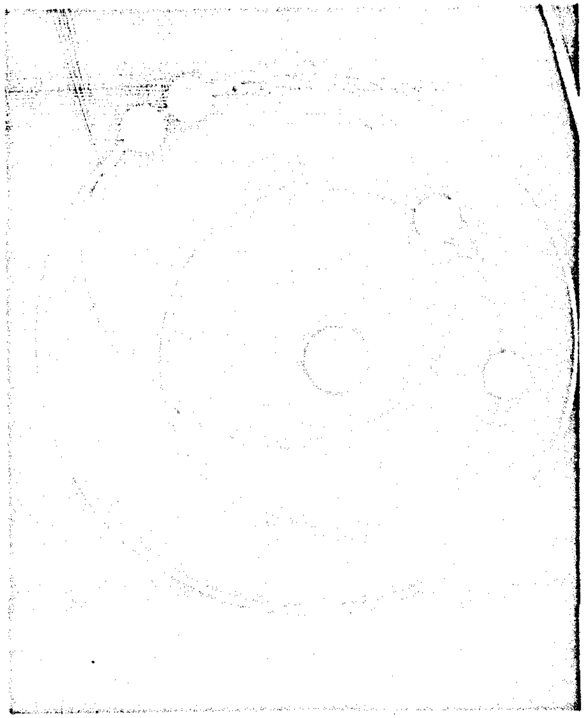




CONJUNCTION



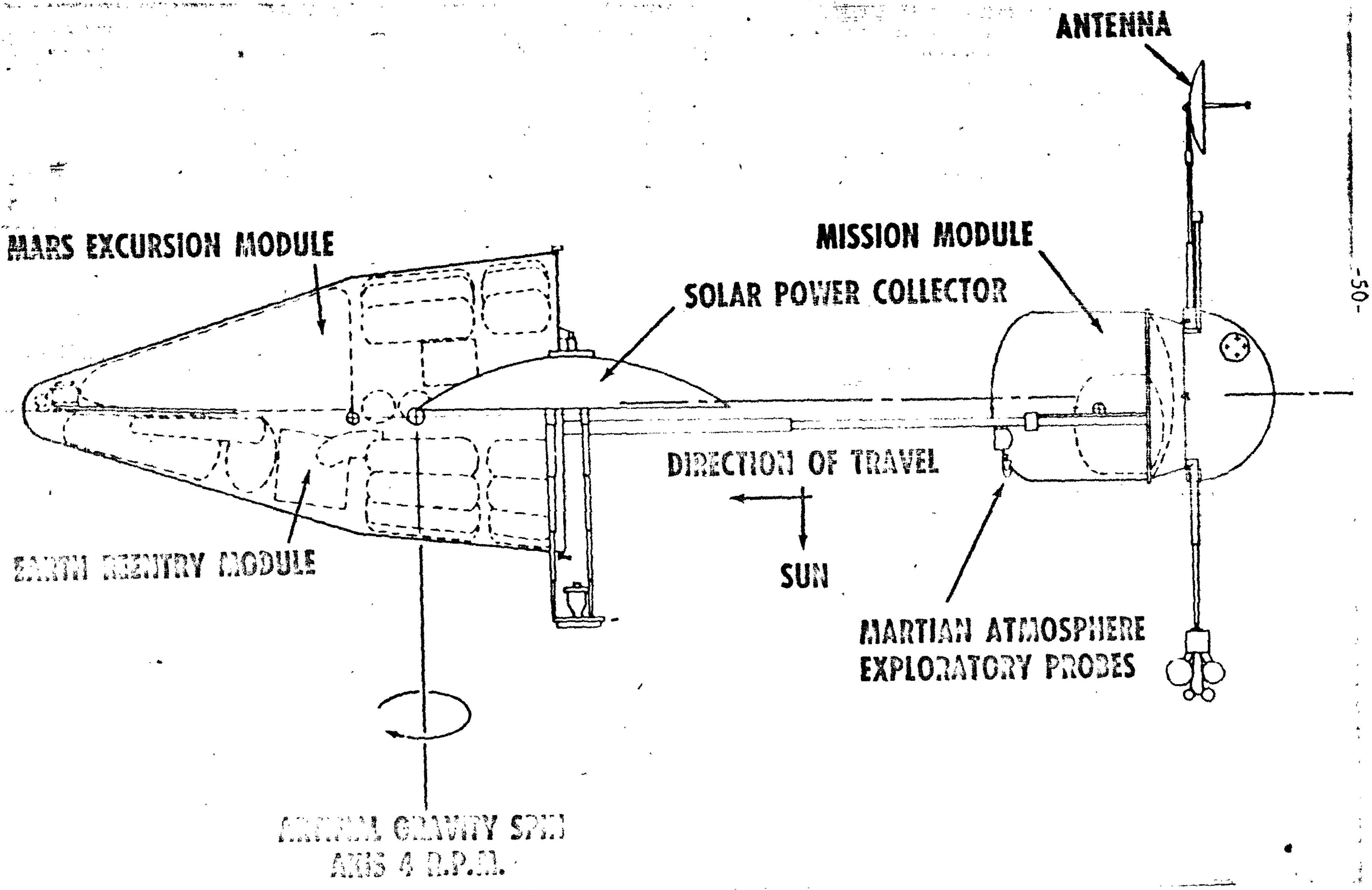
VENUS SWINGBY
(RETURN)



DIRECT

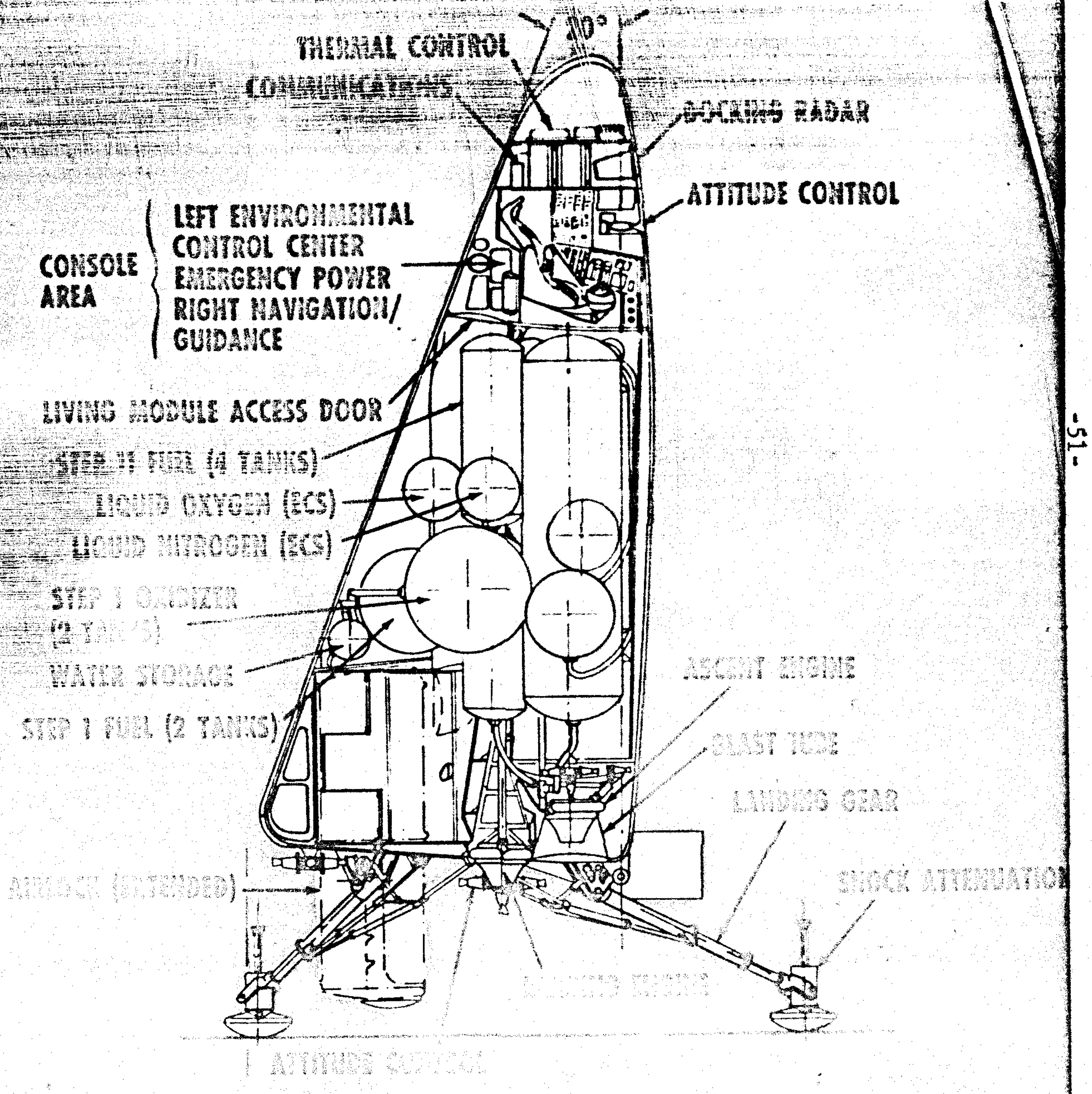
	Δv LEAVE EARTH (1000 FPS)	Δv LEAVE MARS (1000 FPS)	v ARRIVE EARTH (1000 FPS)	DWELL TIME (DAYS)	TRIP DURATION (DAYS)
DIRECT	15	16.5	66	10	430
SWINGBY	15	16.5	44	10	490
CONJUNCTION	14	8.5	39	480	920

MARS LANDING MISSION
MARS AEROBRAKING SPACECRAFT

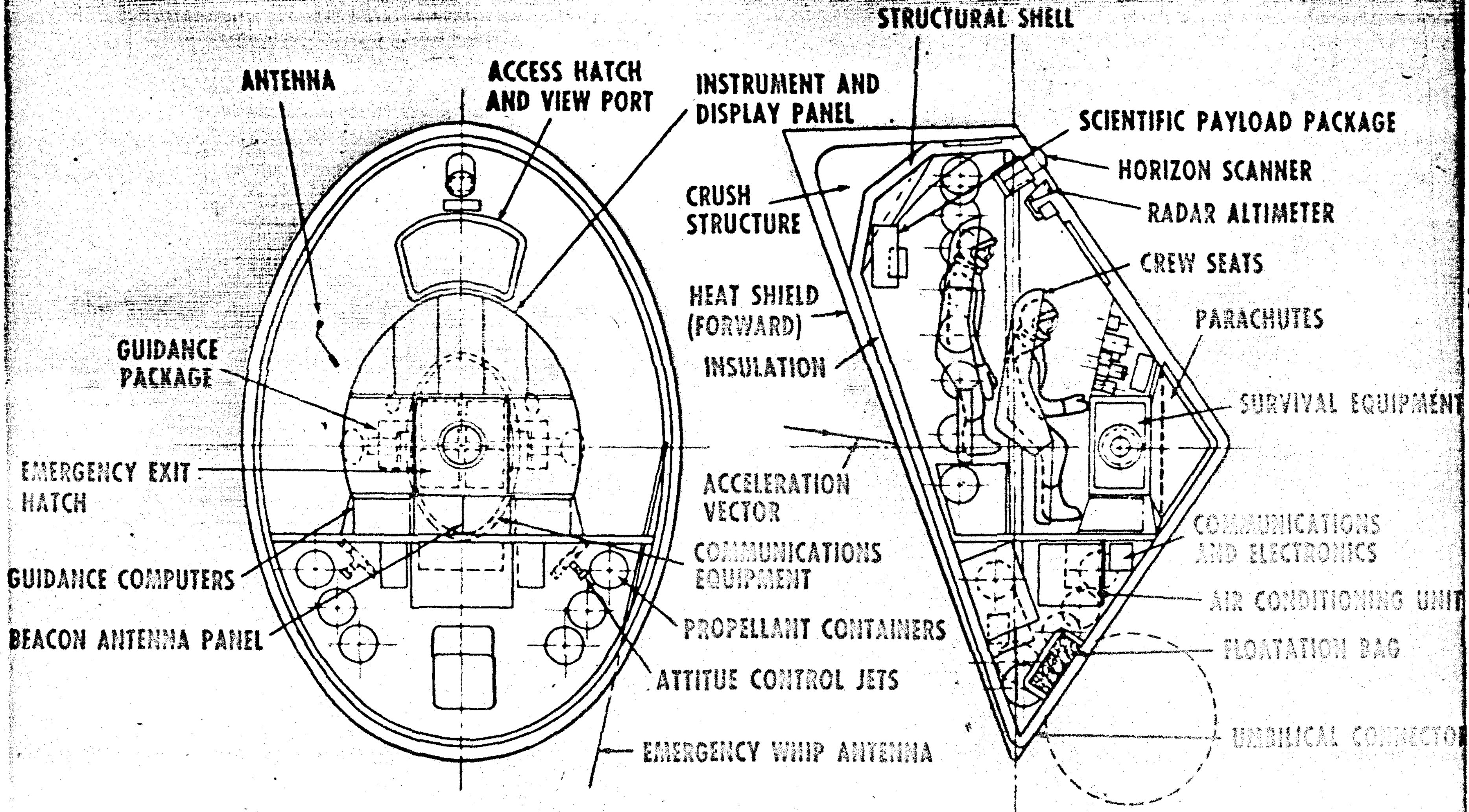


MARS LANDING MISSION

MARS
EXCURSION MODULE



MARS LANDING MISSION
EARTH REENTRY MODULE



VEHICLE WEIGHT- (POUNDS)

EARTH ESCAPE STAGE

	NUCLEAR	CHEMICAL
STAGE (INERT)	215,000	370,000
PROPELLANTS	700,000	2,100,000
PAYLOAD TO ESCAPE	595,000	595,000
IMEO	1,510,000	3,070,000

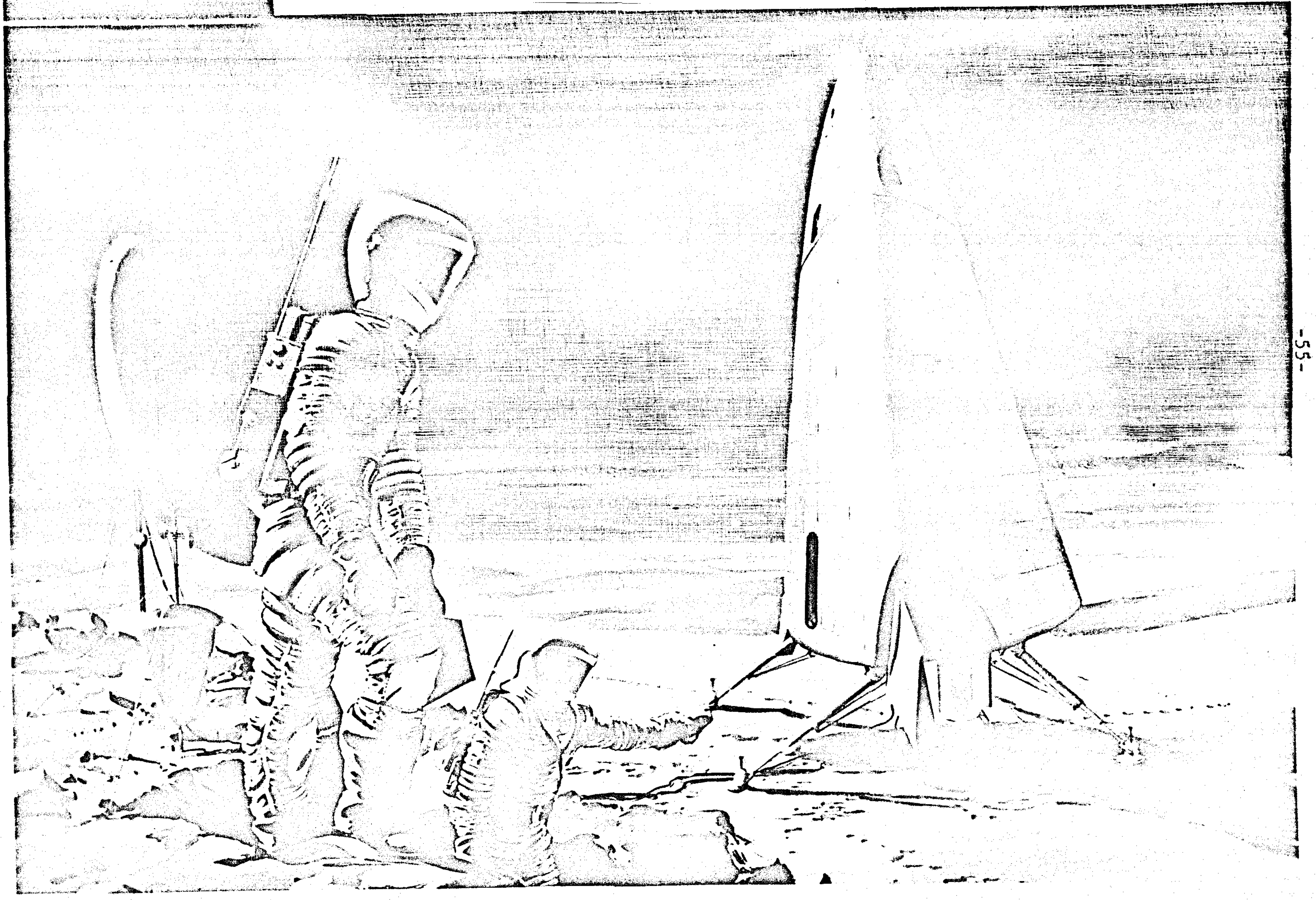
SCIENTIFIC MISSION OBJECTIVES

1. PLANETARY ENVIRONMENT
2. INTERNAL STRUCTURE AND COMPOSITION
3. ORIGIN AND SIGNIFICANCE OF SURFACE FEATURES
4. HISTORY
5. EXISTENCE OF LIFE

1. RELATION TO EARTH'S FEATURES AND HISTORY
2. ORIGIN OF THE UNIVERSE
3. ORIGIN OF LIFE

1. OBSERVATION OF THE UNIVERSE
2. EXPERIMENTATION EXPLOITING PLANET'S UNIQUE ENVIRONMENT
3. ASSESSMENT OF PLANET'S UTILITY AND RESOURCES

MARS EXCURSION MODULE
SURFACE OPERATIONS



PRIORITY OF EXPERIMENTAL DATA COLLECTION

PRIORITY	DATA
1	EVALUATION OF LOCAL HAZARDS PRIOR TO EGRESS
	SEARCH FOR UNFRIENDLY LIFE FORMS
	SOLAR AND PLANETARY RADIATION
	SEVERE TOPOLOGICAL FEATURES
	ATMOSPHERIC CONSTITUENTS
	DIRECTION AND VELOCITY OF SURFACE WINDS
	SURFACE TEMPERATURE
2	DIURNAL VARIATION IN SURFACE PRESSURE, DENSITY, TEMPERATURE, HUMIDITY, AND WIND AND DIRECTION
3	BIOLOGICAL EVALUATION OF LIFE FORMS
4	PHOTOGRAPHIC MAPPING AND RECONNAISANCE
5	SURFACE COMPOSITION
6	SUBSURFACE STRUCTURE
7	TRAFFICABILITY
8	SURFACE BEARING AND SHEAR STRENGTH
9	DIRECTION AND STRENGTH OF MAGNETIC FIELDS
10	MAGNITUDE AND VARIATION IN LOCAL GRAVITY
11	SEISMIC ACTIVITY
12	THERMAL GRADIENT AND THERMAL CONDUCTIVITY
13	VARIATION WITH ALTITUDE OF ATMOSPHERIC PROPERTIES
14	ABUNDANCE AND WEIGHT DISTRIBUTION OF PRINCIPAL ATMOSPHERIC CONSTITUENTS
15	PARTICLE SIZE IN DUST CLOUDS
16	TRANSMISSIVITY
17	SAMPLING OF DEIMOS AND PHOBOS

METEOROLOGICAL EXPERIMENTAL DATA REQUIREMENTS

DIURNAL VARIATION IN SURFACE TEMPERATURE, PRESSURE AND DENSITY

VARIATION WITH ALTITUDE OF ATMOSPHERIC TEMPERATURE, PRESSURE AND DENSITY

ATMOSPHERIC COMPOSITION AT THE SURFACE

ABUNDANCE AND HEIGHT DISTRIBUTION OF ATMOSPHERIC CONSTITUENTS

MEASUREMENT OF SOLAR RADIATION

DIRECTION AND VELOCITY OF SURFACE WINDS

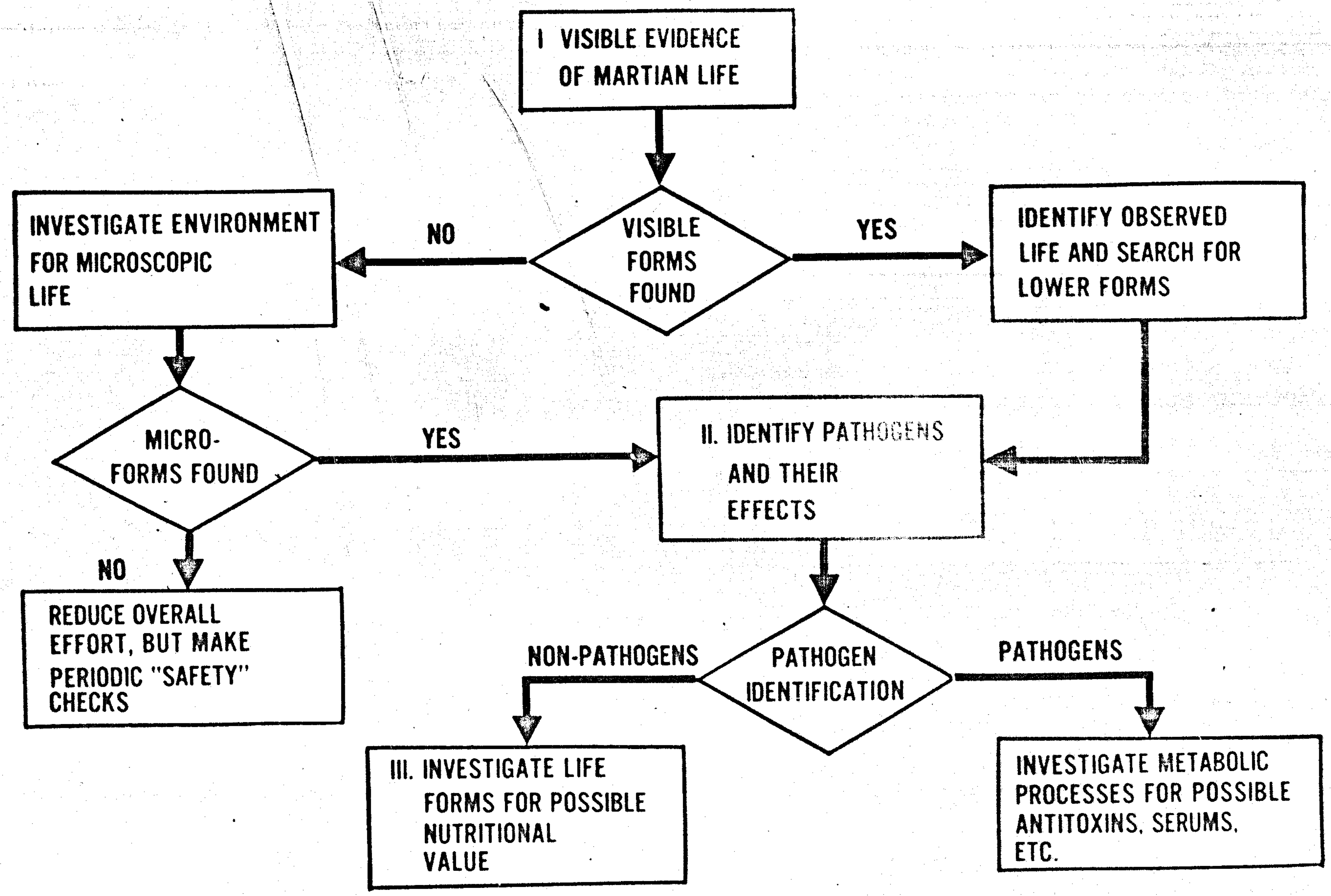
DIRECTION AND VELOCITY OF WINDS AT ALTITUDE

WATER VAPOR

VISIBILITY (TRANSMISSIVITY)

PARTICLE SIZE IN DUST CLOUDS

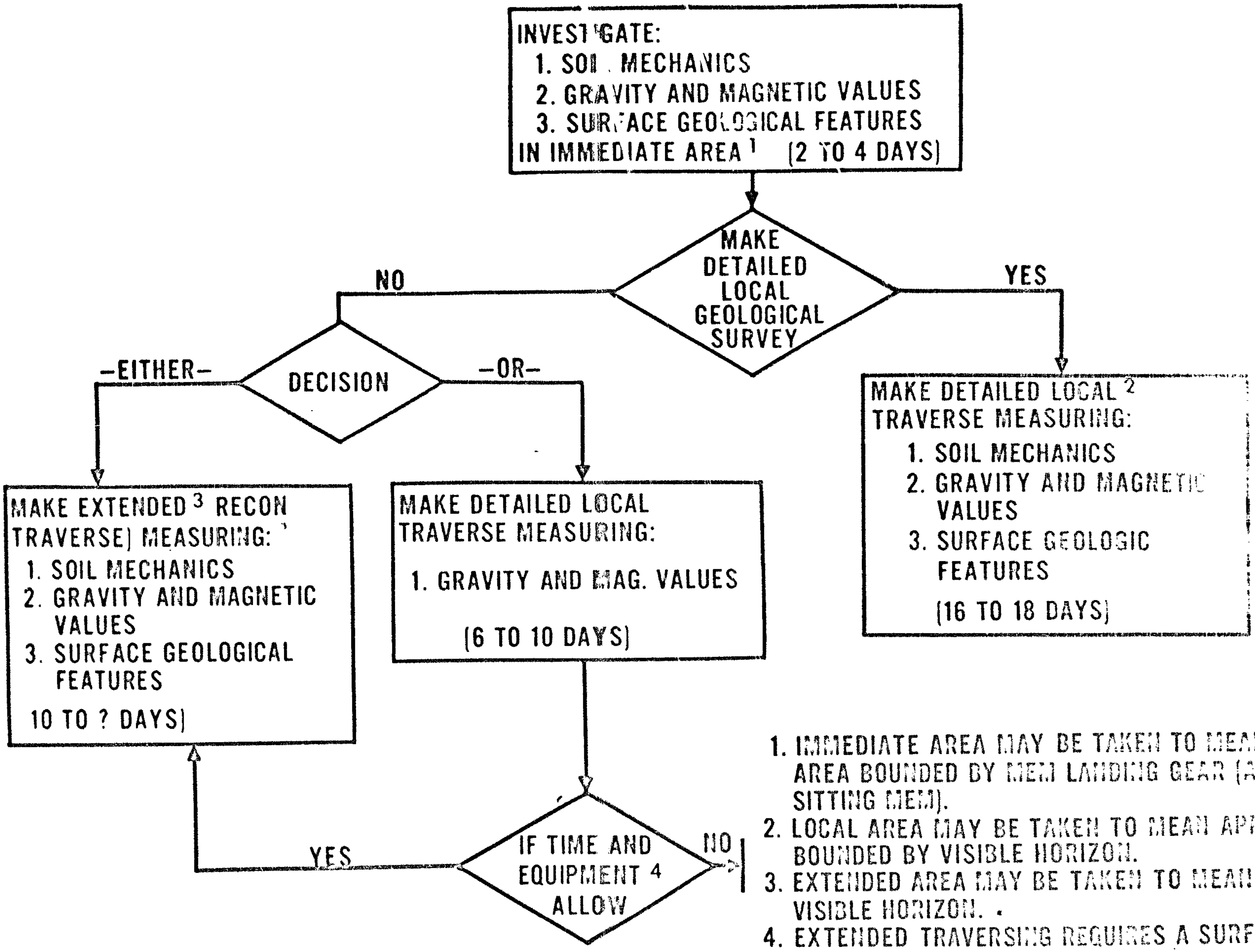
BIOLOGY STUDY PROGRAM



GEOLOGICAL - GEOPHYSICAL EXPERIMENTAL DATA REQUIREMENTS

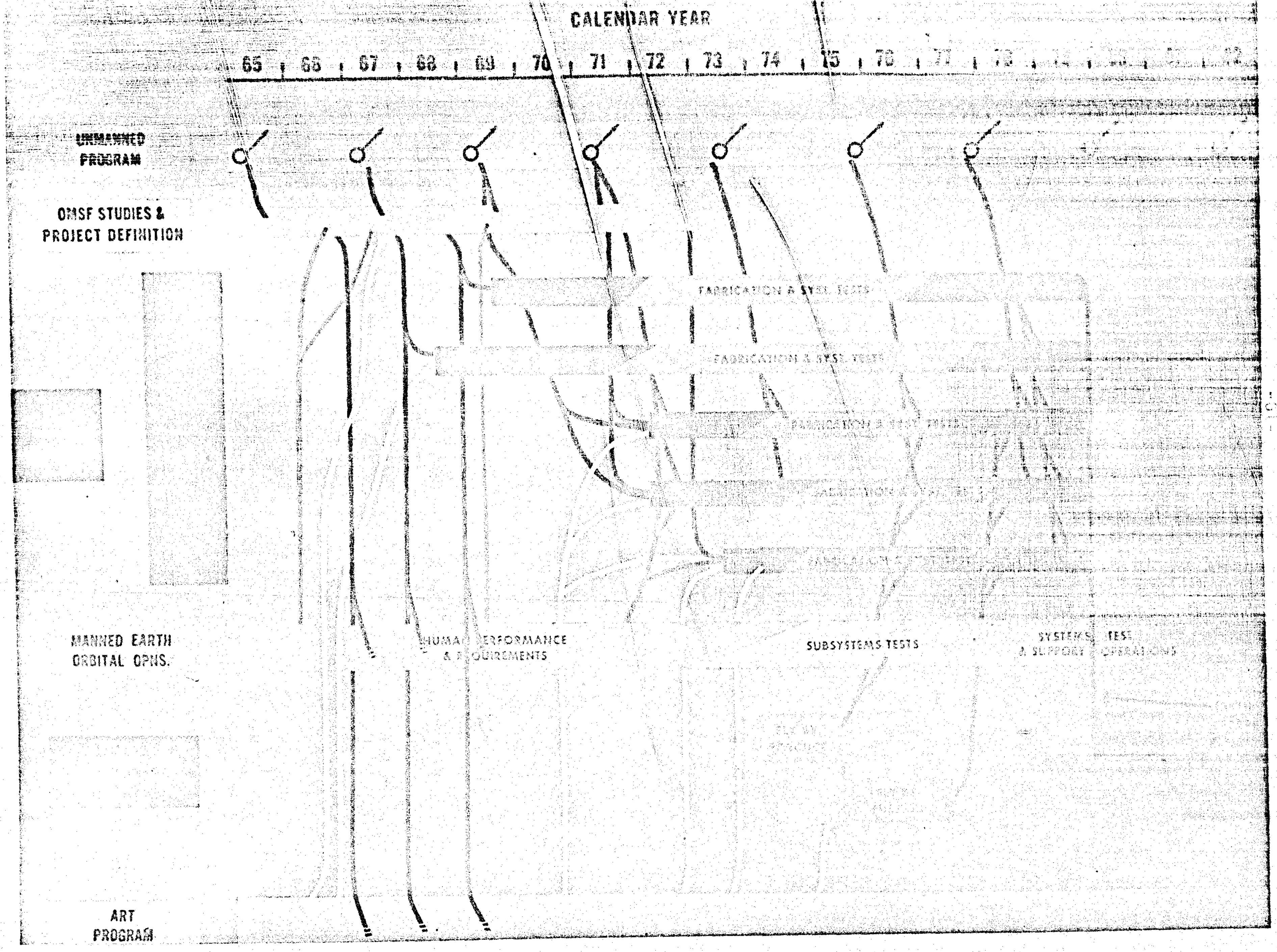
MAPPING OF LARGE AREAS FOR FEATURES OF INTEREST
SURFACE STRUCTURE VARIATIONS
SUBSURFACE STRUCTURE
VOLCANISM
METEORITE IMPACT
SEISMIC ACTIVITY
THERMAL GRADIENT AND THERMAL CONDUCTIVITY
IDENTIFICATION OF MIND MINERAL CRYSTAL STRUCTURES
SURFACE TRAFFICABILITY
SURFACE BEARING AND SHEAR STRENGTH
DIRECTION AND STRENGTH OF MAGNETIC FIELDS
MAGNITUDE AND VARIATION IN LOCAL GRAVITY
FOSSIL EVIDENCE
LOCATION OF WATER
STRUCTURE AND COMPOSITION OF POLAR CAPS
STRUCTURE OF DEIMOS AND PHOBOS

GEOLOGY STUDY PROGRAM

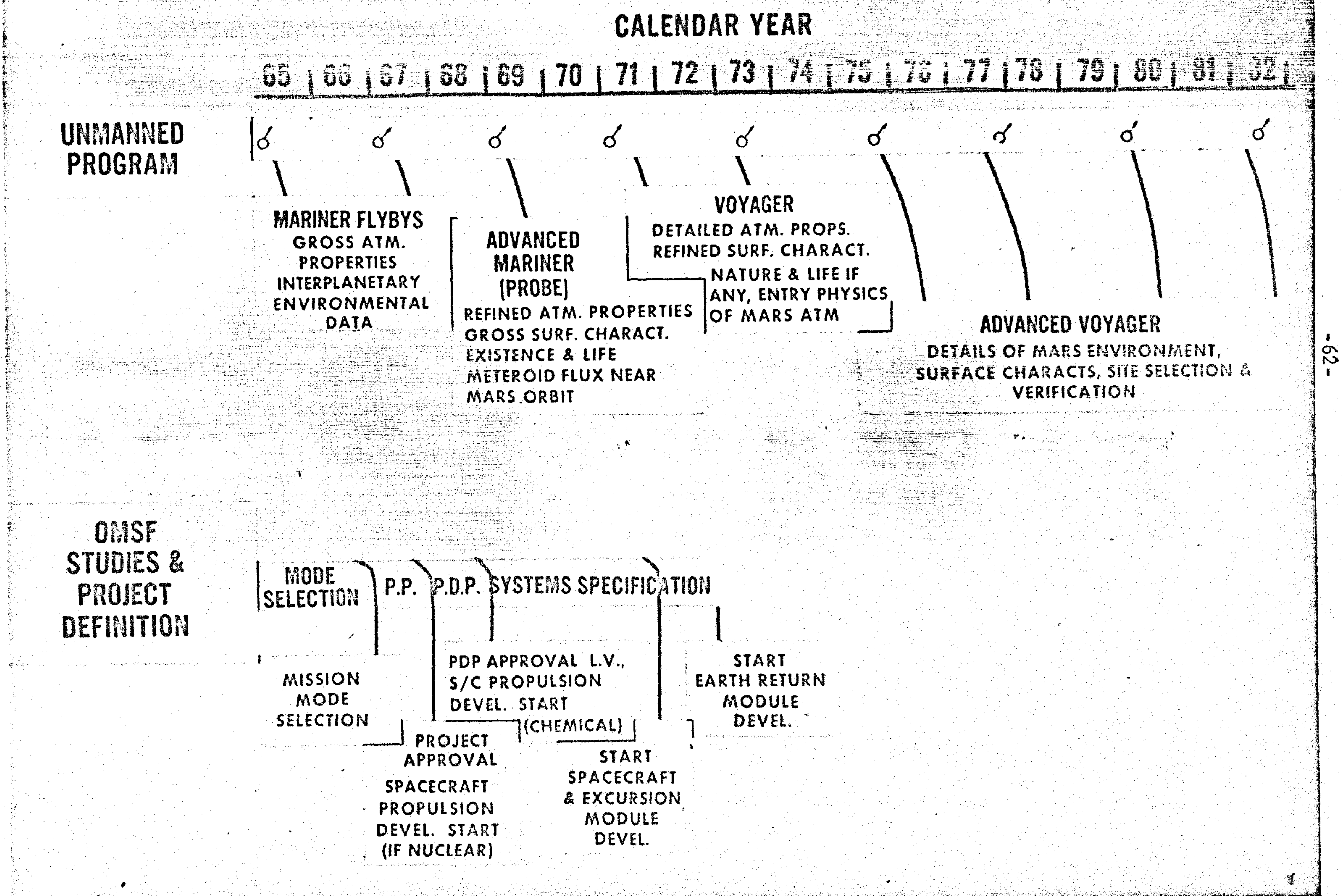


1. IMMEDIATE AREA MAY BE TAKEN TO MEAN APPROX. AREA BOUNDED BY MEM LANDING GEAR (A TAIL-SITTING MEM).
2. LOCAL AREA MAY BE TAKEN TO MEAN APPROX. AREA BOUNDED BY VISIBLE HORIZON.
3. EXTENDED AREA MAY BE TAKEN TO MEAN OUTSIDE VISIBLE HORIZON.
4. EXTENDED TRAVERSING REQUIRES A SURFACE VEHICLE.

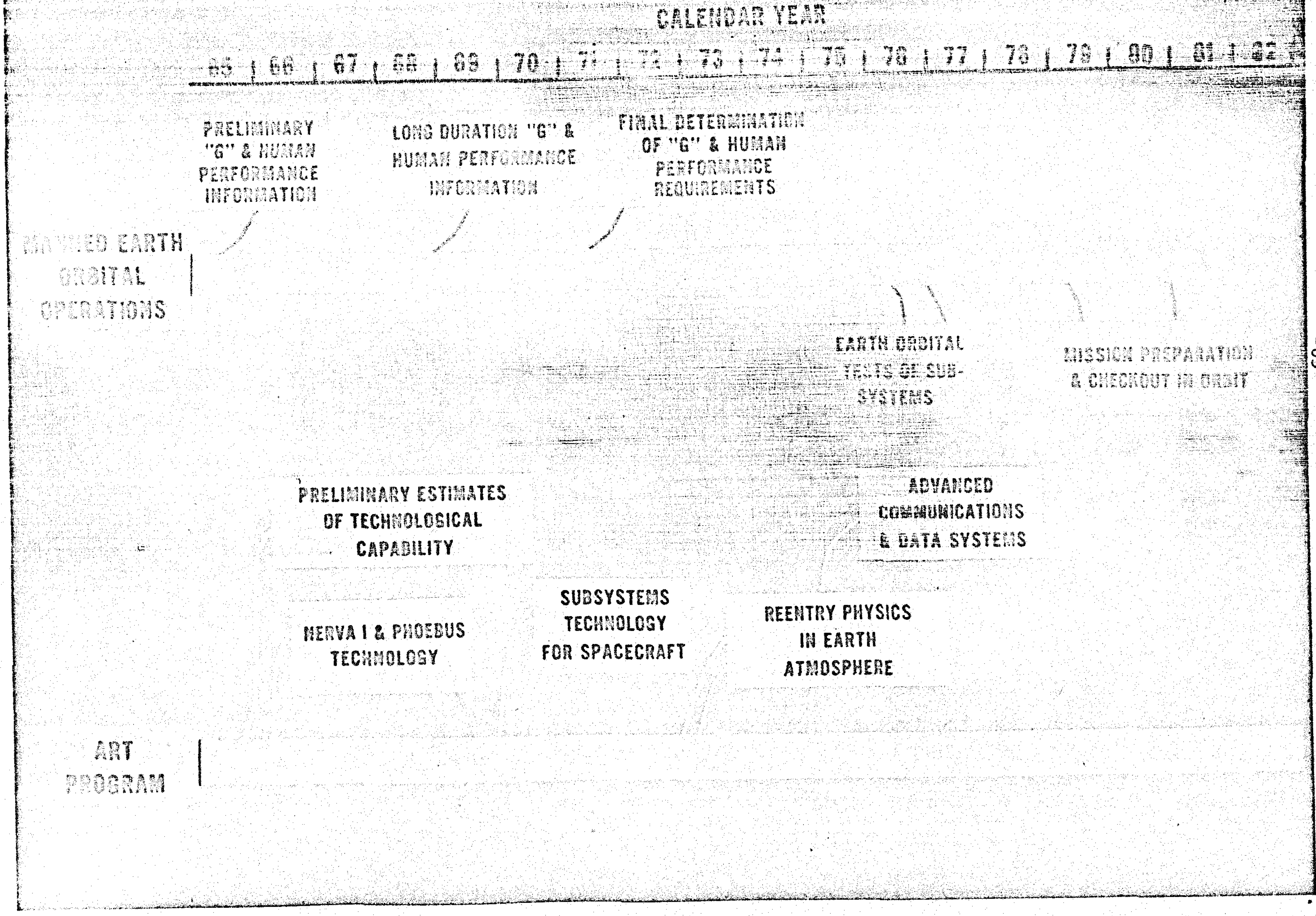
MANNED MARS LANDING MISSION DEVELOPMENT SCHEDULE



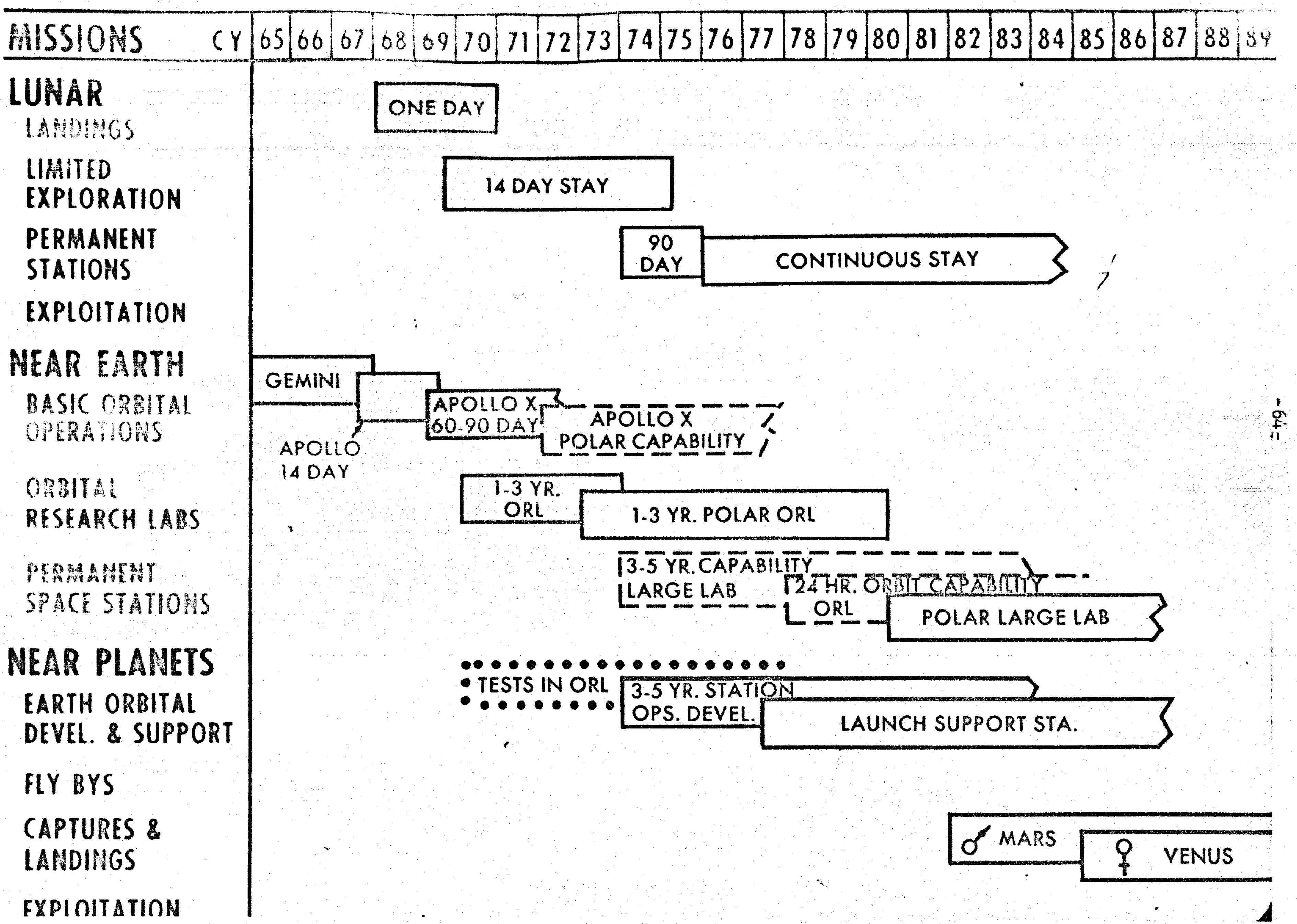
MANNED MARS LANDING MISSION DEVELOPMENT SCHEDULE MILESTONES



MANNED MARS LANDING MISSION DEVELOPMENT SCHEDULE MILESTONES



MANNED MISSIONS SCHEDULE PLAN II



APPENDIX D

[*]Policy Resolution Concerning Quarantine of Materials of Planetary Origin

WHEREAS

A. The technological capability for roundtrip space missions may be achieved by this and several other nations within the next ten to twenty years.

B. Such return missions from other planets may allow for the implantation on the earth of organisms whose biological capacities are at present unknown.

C. Such organisms may include many types unable to survive on earth, or having a neutral ecological value, or even of important benefit to industry, agriculture or medicine; however, they may also include types that might be seriously deleterious to the health of economy of man. (See Footnote, page

D. The protection of public health and the maintenance of agricultural quarantines are presently within the jurisdiction of several national agencies which have had considerable experience and expert knowledge in dealing with related problems; however, they have not evidently actively concerned themselves with the impending problems of planetary quarantine.

E. Policy on space missions, as it concerns the activities of other sovereignties and the welfare of all people, must involve our international relations. In due course, the World Health Organization will inevitably take an interest in interplanetary quarantine, and other organs of the United Nations may also be expected to do so. The United States should take statesmanlike leadership in such an area, rather than be made to seem to comply reluctantly with the pressure of external opinion.

F. The development of sound policy on interplanetary quarantine has important implications for the planning of future space missions. On the other hand, present scientific knowledge

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[*] Material from the minutes of the February 1960 meeting of the Exobiology Committee of the Space Science Board, National Academy of Sciences, Washington, D. C.

limits the reliability of any conclusions, and must be exploited to the fullest possible extent.

G. The National Aeronautics and Space Administration has primary operational responsibility for space science and exploration; however, it cannot be expected to take responsibility for policy questions primarily concerned with public health.

H. Although one or more decades may elapse before return vehicles actually can function, considerable time is needed for the assessment of policy, for planning space missions, and for intercurrent research.

THEREFORE BE IT RESOLVED by the Space Science Board of the National Academy of Sciences that the following recommendations be transmitted to the Administrator of the National Aeronautics and Space Administration.

1. That he join with the Surgeon-General of the United States Public Health Service in establishing an inter-agency committee on interplanetary quarantine, with representation from such agencies as National Aeronautics and Space Administration, the Public Health Service, Department of Agriculture, Department of Defense (Biological Warfare Defense), Department of State, and others; that this committee be charged with the formulation and timely review of a national policy on interplanetary quarantine; and the committee be advised by experts in the various relevant sciences from within the agencies and from civil life.

2. That the requisite organization be established within the National Aeronautics and Space Administration to represent it in the formulation and administration of policy in space biology, and to develop the research programs that are therefore urgently needed.

Footnote

While many scientists have already concluded that back-contamination is a serious and tangible threat, or should be regarded as such until we can be sure otherwise, others feel that the risks are very small and should be disregarded. Except to report that the magnitude of the risk is at least controversial, we need not anticipate the further findings of the committee whose establishment is being recommended herewith. The main arguments take the following form:

APPENDIX E

* VI. Back-Contamination

The introduction into the Earth's biosphere of destructive alien organisms could be a disaster of enormous significance to mankind. We can conceive of no more tragically ironic consequence of our search for extraterrestrial life.

Several members of the Summer Study, as well as many of our colleagues in the scientific community, feel great concern over the possible consequences of back-contamination. On the other hand, some members consider the danger negligible.

Nearly all known pathogens have evolved in association with their hosts so extraterrestrial organisms are not likely to be pathogenic. Nevertheless, there are some exceptions which give rise to diseases of man -- viz., psittacosis, aspergillosis, botulism, and tetanus. Also, recent work demonstrating that ribonucleic acid of tobacco mosaic virus can direct specific protein synthesis using the protein synthesizing system of E. coli should caution us that the host specificity of viruses may not necessarily be more pronounced than that of the pathogenic protista. Moreover, in a different environment adaptation may take a different turn -- illustrated by the observation that the virulence of many microorganisms for a particular host can be greatly increased by successive passages through this host. Therefore, it seems conceivable that originally harmless forms of extraterrestrial life may on the Earth acquire pathogenic characteristics. Such potentiality will be hard to judge when the organisms are first encountered.

In any case mankind is far from helpless against introduced pathogens. By anticipating danger, we can minimize it.

> RECOMMENDATION: To reduce the danger of back-contamination, appropriate quarantine and other procedures should be employed when handling returned samples, spacecraft, and astronauts. NASA should do all in its power to make the risk as small as possible.

Surely many unmanned one-way missions to Mars will be carried out before a round trip becomes feasible. Much will be learned from these early explorations and we are confident that this will include information on the possible hazard of back-contamination. Thus we shall acquire solid knowledge to replace guesswork about whatever danger may be involved.

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*Taken from Chapter 9, Review of Space Research, National Academy of Sciences-National Research Council Publication 1079, 1962.

1. Are other planets in fact inhabited by micro-organisms?

   The evidence at least for Mars is sufficiently encouraging to warrant substantial effort in constructing experiments to detect life there despite great technical difficulties, however, at least a landing will be required to be sure.

2. Could such organisms grow on earth?

   This cannot be predicted in advance. However, many species of terrestrial bacteria would grow on Mars, as far as we can judge by our knowledge of their requirements and of the environment.

3. Could such organisms be harmful to man?

   This question elicits the sharpest division of opinion.

   Pathogenicity for man on the part of most organisms seems to require the evolution of very elaborate adaptations to allow for transmissions from one infected individual to a new host, and to invade the host tissues despite natural defenses. Microbial pathogenicity would have evolved only in company with quasi-human hosts, and even so these pathogens would be poorly adapted to attack terrestrial organisms which would be biologically novel for them.

   The counterarguments would be that our natural defenses against infection represent our own evolved adaptations against terrestrial bacteria and viruses; they may require the presence of familiar proteins and carbohydrates to recognize the invading organisms as foreign. Planetary organisms with a distinctive chemistry might not be recognized as foreign, and therefore not elicit an adequate response. Furthermore, new organisms might cause serious economic harm even if they are not pathogens for man.