NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL
Division of Medical Sciences

PANEL ON EXTRATERRESTRIAL LIFE
(Panel 2)
of the
Armed Forces-NRC Committee on Bio-Astronautics

Minutes of First Meeting
16-24 July 1959
Woods Hole, Massachusetts

ATTENDANCE:

Panel: Dr. Melvin Calvin, Chairman.
Dr. Wolf Vishniac, Vice Chairman,
Mr. Richard W. Davies, Dr. Matthew Meselson,
Mr. Carl E. Sagan, and Dr. Harold Weaver.

(Absent) Dr. George E. Hutchinson and
Mr. Malcolm D. Ross.

Ex officio,
Executive Council: Major Kay Cutler, USAF (MC).

Liaison Representatives:

U. S. Army: Dr. Richard S. Young, Research Projects Laboratory Army Ballistic Missile Agency, Redstone Arsenal, Alabama.

National Aeronautics and
Space Administration: Dr. Gerhard Schilling, Chief, Astronomy and Astrophysics Program.
Dr. Douglas L. Worf, Program Chief, Life Biology and Life Support Systems.

Guests: Dr. C. H. Sederholm, Department of Chemistry, University of California, at Berkeley,
Dr. Fred Whipple, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts.

National Academy of Sciences
National Research Council: Mr. George A. Derbyshire, Space Science Board.
Dr. H. Burr Steinbach, Chairman, Division of Biology and Agriculture.

Abstract

Mission and Introduction.

Panel 2 is concerned primarily with the biology of extraterrestrial life.

I. Decontamination.

It is of utmost urgency to prevent contamination of the Moon and planets by terrestrial organisms, while initial explorations of the Solar System are under way. Contamination of any celestial body may irretrievably destroy data concerning the origin of life and in an explosive manner upset planetary ecologies.

II. Exploration of the Solar System for Organic Molecules and Living Matter.

Techniques and approaches are suggested which may be useful in collecting evidence for the existence of extraterrestrial life.

III. Terrestrial Studies in Support of Solar System Explorations.

Extensive basic work is needed to facilitate the interpretation of data collected by space probes. A partial list of necessary studies is given here, together with suggested literature compilations which would facilitate such work.

IV. Conclusions and Recommendations.

Insure the sterilization of space probes. Attempt to obtain international agreement to prevent biological contamination of celestial bodies. Establish laboratories and an observatory devoted to the study of the Solar System and to necessary supporting work. Evaluate research proposals. Sponsor meetings.

INTRODUCTION AND MISSION

No great question has occupied Man's mind longer than that of his own origin. Scientific investigations of life have heretofore been confined to one small sample of the universe: Earth. Space vehicles now open to Man the wide expanse of the Solar System, and present to the scientist a host of new samples of the universe -- the planets and their satellites and the thinly scattered material in the vast space between the planets, the debris remaining from the birth of the Solar System as well as interstellar material now in the region of the Sun. We cannot afford to neglect this newly opened field of research. The new information we shall gain will be of the greatest importance to astronomy, to physics, to chemistry, to biology. It will be of the greatest interest to all thinking men; it cannot fail to exert a profound influence on Man's philosophy.

Panel 2 considers its mission to be the stimulation and promotion of such researches, of all studies concerned with the origin and nature of life in the Solar System and beyond.

To implement these aims we consider the following activities to be within our sphere:

1. Consideration of existing pertinent knowledge.

2. Consideration of the type of investigations, both observational and experimental, which might contribute to this knowledge.

3. To be available both individually and collectively to the various agencies of the Government or to the National Academy of Sciences to help in the selection and encouragement of work.

4. To take steps to facilitate the exchange of information between various groups concerned with the problem -- sponsoring meetings, etc.

5. To take immediate steps toward international agreement designed to preserve whatever information might be available to us on other celestial bodies -- agreements on decontamination, etc.

I. The Protection of Extraterrestrial Bodies from Biological Contamination

There exists the grave possibility that without sufficient thought and preparation we may unwittingly and irretrievably destroy critical evidence concerning the origin and early history of the Solar System, and the origin and prevalence of life in it. The danger is that we may accidentally deposit terrestrial organisms on the surface of the Moon and planets.

A. Astrobiological Background.

1. Origin of Organic Matter and Life in the Solar System.

Although there is much uncertainty on the detailed evolution of the Solar System, there is good reason to believe that the Moon and planets arose from a vast cloud of gas and dust in which (aside from helium) hydrogen, carbon, nitrogen, and oxygen were the most abundant elements (Kuiper, 1952; Urey, 1952). In their later stages of formation these bodies were surrounded by envelopes primarily composed of H_2, CH_4, NH_3, and H_2O. It is known that when such a mixture of gases is supplied with energy -- for example solar ultraviolet radiation, electrical discharges, or heat, a variety of organic molecules is produced (Miller, 1955; Oparin, 1958). Organic molecules produced in primitive planetary or lunar atmospheres would have drifted down to surface levels where solution in liquid water or other media could occur. As much as 10 gm. of organic matter may have been deposited on each square centimeter of the lunar surface before the lunar atmosphere escaped into space (Sagan, 1959). Under such circumstances, self-replicating systems may have originated on several bodies of the Solar System in addition to the Earth.

Several observations of Mars suggest the presence of living material (Dollfus, 1958; de Vaucouleurs, 1956). Although there is no direct evidence of the origin and survival of life on the Moon, it may be possible that beneath the present surface material, there lie the remains of primitive lunar organisms. Even if life never arose on the Moon there may still be organic matter lying beneath the surface. Verification of either of these hypotheses would be of the greatest significance.

The Moon is important in another respect: It is the only large body near the center of the Solar System, undisturbed by wind and water. It holds information concerning material which has fallen on it through its five billion-year history. Cometary and interstellar organic matter may have accumulated in measurable quantities. In addition, it would be a trap for the hypothetical cosmobiota, microorganisms carried through space and deposited on lunar and planetary surfaces.

2. Circumstances of Biological Contamination.

There are various ways in which the Moon and planets may be contaminated, depending upon the properties of the bodies.

a. A Solar System body may contain no living indigenous organisms and may be incapable of supporting terrestrial organisms. There may nevertheless be relics of primitive indigenous organisms and deposited cosmobiota on or beneath the surface. Especially on a low-gravity, high-vacuum body such as the Moon, a vehicle impacting at, or near, escape velocity (2.2 km./sec. for the Moon) should distribute its contents over an appreciable fraction of the body's surface area. In subsequent attempts to detect primitive life forms and cosmobiota, it might be impossible to distinguish among the three possibilities: primitive indigenous organisms, cosmobiota, or terrestrial microbiological contamination.

b. A body may contain no indigenous living organisms, but may be capable of supporting terrestrial organisms. In addition to observing evidence on primitive indigenous organisms and cosmobiota, the possibility exists that a deposited terrestrial microorganism, in the absence of biological competitors or predators, will reproduce at a rate limited only by the availability of water and metabolites. The common bacterium Escherichia coli has a mass of 10^{-12} grams and a minimum fission interval of 30 minutes. At this rate it would take 66 hours for the progeny of one bacterium to reach the mass of the Earth. The example illustrates that a biological explosion could completely destroy the remains of prebiological syntheses. The time scale of biological explosion need not be long;

Indeed, it may be much less than the interval between oppositions for the planets. Evidence may be destroyed because of one impacting probe before observations can be made by another probe at the following opposition.

c. A body may contain indigenous living organisms. There is then the possibility that deposited terrestrial microorganisms, by competition with or parasitism upon even one species of extraterrestrial organism, may completely upset the planetary ecology. Before another probe is launched the destruction of many or even all the indigenous organisms on the contaminated extraterrestrial body may be complete.

In this context should also be mentioned the possibility of back-contamination; i. e., that return voyages from extraterrestrial bodies may carry with them virulent extraterrestrial or modified terrestrial organisms. If such organisms are introduced into human or other terrestrial populations there exists the definite possibility of pendemics and the destruction of the existing terrestrial ecologies.

B. <u>Tolerance Recommendations</u>.

Present ignorance of lunar and planetary conditions and our inability to anticipate reliably the nature of possible extraterrestrial life or pre-life forms constitute strong reasons for the exercise of maximum caution. It is possible that the Moon or any one of the planets is capable of supporting some form of terrestrial life and that a single viable terrestrial organism could multiply sufficiently to cause a catastrophic derangement of pre-existing conditions. Until this possibility can be confidently excluded no landing can be risked which entails a significant probability of depositing a viable organism. These considerations provide a basis for the establishment of contamination tolerances for space probes. THIS PANEL RECOMMENDS THAT DURING THE PERIOD OF INITIAL EXPLORATION OF ANY ESTRATERRESTRIAL BODY THE PROBABILITY OF LANDING ONE VIABLE ORGANISM BE KEPT BELOW ONE IN 10^6. If the number of probes to be launched and the probability of impacting are not easily estimated, then the above tolerances of one viable organism in 10^6 must be applied to each probe. It follows that it is pointless for a single nation to sterilize its probes; therefore we urge the Executive Council to request the President of the National Academy of Sciences to initiate international negotiations on this matter.

It would seem highly unlikely that dead organisms or their fragments could initiate large-scale modifications of a planetary surface. However, this possibility cannot be fully discounted at present, and, consequently contamination by dead organisms, their fragments, and vehicular materials of biological origin should be held to a minimum. Even if such materials can not act catalytically to alter pre-existing conditions, their concentration must be kept so low as not to jeopardize the possible discovery of similar materials of extraterrestrial origin. Studies should be pursued of the possible catalytic effects of organic molecules on organic media likely to be found on or beneath planetary and lunar surfaces.

The microorganism population of a mammal may be as high as 10^{12}. THEREFORE, UNTIL MORE INFORMATION IS AVAILABLE ON THE NATURE AND DISTRIBUTION OF ORGANIC MOLECULES AND LIVING ORGANISMS, NO LANDING OF ANIMALS OR MEN SHOULD BE ATTEMPTED ON THE MOON OR PLANETS, ESPECIALLY WHERE THERE EXISTS APPRECIABLE POSSIBILITY OF HARD LANDING. A program should be initiated for biological and chemical analysis of lunar and planetary surface and subsurface materials, by instrumented, unmanned, sterilized, soft-landing probes.

On worlds where further analysis indicates considerable danger of contamination, manned soft landings should be safeguarded by sophisticated decontamination techniques. Decontamination should be standard procedure during each air-lock operation, both on leaving and on re-entering the vehicle. Decontamination upon leaving an extraterrestrial body must be no less thorough than on leaving Earth. Space suits must be designed to eliminate cracks and joints in which microorganisms might lodge inaccessible to decontamination techniques. In the light of present knowledge these remarks must apply in particular to the Moon, Mars, and Venus, as well as to other bodies of the Solar System.

C. Sterilization and Decontamination of Space Probes.

Adequate sterilization and decontamination can be achieved only by careful and early consideration of the design and construction of payloads. It cannot be assumed that sterilization will be affected by interplanetary radiation, re-entry heating, or explosion upon landing. Microorganisms within the interior or in the surface crevices of a probe are likely to be protected from interplanetary radiation. Adequate re-entry sterilization is unlikely to occur; meteorites are known to have reached the Earth's surface without experiencing interior temperatures sufficient to kill microorganisms. Furthermore, sufficiently small contaminated particles, such as might result from the accidental fragmentation of a probe, would be able to descend through a planetary atmosphere without appreciable heating. Finally, microorganisms are known to survive chemical explosions; hence we can recommend that the impact of a probe on a planetary surface cannot insure sterilization. In the case of soft landings, it might be possible to seal contaminated objects so securely as to prevent their escape. However, this procedure may lack the high degree of reliability recommended on page 5.

Soft landings carrying terrestrial life, for example manned landings, should not be attempted until information about the extraterrestrial target is sufficient to insure the target's insensitivity to terrestrial biological contamination. In any case extensive samples of lunar and planetary surfaces and atmospheres should be gathered and safely stored for future examination before terrestrial contamination is allowed to occur.

The above considerations lead us to conclude that the sterility of a probe must be insured by procedures initiated long before the time of launching. At present it is possible to anticipate and recommend five phases of payload sterilization for all deep space missions. They are in sequence:

1. Sterile fabrication and assembly of components, particularly those which might be damaged by subsequent heat, chemical, or radiation sterilization procedures.

2. Built-in or intrinsic sterilization of parts.

3. Terminal sterilization.

4. Maintenance of sterilization.

5. Decontamination procedures.

Finally, suitable microbiological testing and control procedures must be integrated into the sterilization operation.

1. Sterile Fabrication and Assembly. The removal of dust and foreign particles from the space probe eliminates a major source of biological pollution and it is at the same time an engineering virtue. The washing and scrubbing of parts of the payload with water and detergents or other acceptable solvents can reduce the number of microbes on the probe by several orders of magnitude.

Sterile assembly will also include the use of presterilized components. Parts such as screws and bolts can be heat sterilized. If screws and fitting holes are made to fit exactly then care must be taken to sterilize them before joining them. If fittings are not perfectly joined, geseous antiseptics such as ethylene oxide may be used to penetrate and sterilize these interstices.

2. Built-in Sterilization. Whenever possible, substances which are lethal to organisms should be employed. Germicidal substances might be incorporated into lubricants and sealing compounds and even more generally used in the fabrication of components. Certain substances of biological origin such as casein glue or shellac should be avoided.

3. Terminal Sterilization. Microorganisms perish when subjected to dry steam at 160° centigrades for 20 minutes (Halvorsen, Bacterial Spores, 1957). However, some of the components which go into payloads, with which we are now familiar, can not endure this temperature. A more generally applicable disinfectant is ethylene oxide gas (Phillips and Kaye, 1949).

Ethylene oxide is a small molecule and therefore dissolves in many substances such as rubber, plastic, and oil. It is quite penetrating and will work its way into the interstices of most components.

In many instances where neither heat nor gas sterilization is practical radiation is a possibility. Doses of the order of 10^7 rads are required for good sterilization (Hollaender, 1952). Some component materials, perhaps battery interiors, can be subjected to this intense radiation without injuring their performance. The 1.17 and 1.33 MEV gamma rays from Co^{60} make this a useful radiation source for sterilizing small packages.

4. Maintenance of sterilization. After having obtained a sterile space probe it will be necessary to mount it on the rocket boosters. The technical problem is then one of keeping microbes from coming into contact with the probe.

The probe is encased in a protective metal shroud during the launch phase of the space flight. The shroud can be employed to house a disinfectant atmosphere throughout the count-down and flight through the atmosphere, after which it is discarded. The disinfectant can be either carboxide or a faster-acting, less penetrating, gas such as beta-propiolactone.

5. Decontamination Procedures. It is difficult to suggest specific procedures for probe decomtamination, as distinct from sterilization, without increased knowledge of the possibility of serious derangement of extraterrestrial conditions by nonliving terrestrial material. The use of materials of biological

origin should be shunned in payload design, and in any case a detailed chemical inventory should be kept of the quantities of all materials deposited upon extraterrestrial surfaces. If possible, a duplicate payload should be placed in careful storage.

II. Exploration of the Solar System for Organic Molecules and Living Matter.

In spite of the long history of observational astronomy, our knowledge of many fundamental properties of the Solar System is severely limited. During the past few decades astronomy has been reborn in physics. Astrophysics has taken great forward steps, but relatively few new facts about the Solar System have been discovered and thoroughly investigated. Except for the work of a small number of widely known individuals, Solar System astronomy has languished. New methods and new instruments have been applied to the study of the Solar System far less often than they have been to the study of the stars. All too infrequently have physicists, geophysicists, chemists, and microbiologists joined the astronomer to supply new approaches to the study of the planets. Science and Man's advance into space require that detailed knowledge of all aspects of the Solar System be available. Every effort must therefore be made to vitalize and expand astrophysical and astrobiological studies of the system.

A. Observations from the Surface of the Earth.

1. Some available Observations.

Few observational data relate directly to the question of the existence of life, or, in the broader view, of organic, life-related molecules on the planets. The information that does exist has been gained from visual telescopic observations, light polarization studies, spectroscopy, and radioastronomy.

The planet Mars has held the greatest interest for many observers because of the so-called canals (Schiaparelli, 1877), objects whose nature and existence is still hotly disputed, and the circumstantial evidence for life provided by the equatorward advance of dark areas in one hemisphere of the planet (Lowell, early part of this century) as the winter polar cap of that hemisphere retreats with the advance of the Martian season of spring. The polar caps are known to be composed of hoar frost (Kuiper, 1952; Dolfuss, 1958). Dense water clouds as we know them on Earth do not exist on Mars. It has been generally stated that liquid water would occur on the surface only under very unusual circumstances, though this statement appears to be seriously in error (Sederholm, Weaver, and Sagan, 1959) if salts are present on the surface of the planet. Dried-up seas would have deposited salts; It is difficult to imagine the surface of a planet free from such salt deposits. In the region of such deposits one could now find water, derived from the Martian atmosphere, and present in liquid form despite the low temperature and vapor pressure. It is tempting to try to relate salt deposits from the ancient seas to the present dark areas of the planet.

Studies of the polarization of reflected light from the surface of Mars (Dollfus and others, 1948-1959) show that the polarization properties of the dark areas change with the advance of the Martian season while polarization properties of the desert areas do not. The polarization curves and their variations indicate that the reflecting surface of the planet, responsible for the polarization, must be composed of minute grains; and that the average size of absorption (or both) of the grains in the dark regions increases as the Martian season advances.

Infrared spectra of the dark areas of the planet (Sinton, 1957, 1958) show reflection minima in the wavelength region 3.4 to 3.7 microns, ascribed to the C-H chemical bond.

The outer planets, excepting Pluto, possess extensive reducing atmospheres, probably containing large amounts of hydrogen and helium. Methane and ammonia have been detected spectroscopically in the atmosphere of Jupiter and Saturn, as has methane in those of Uranus and Neptune. Ammonia undoubtedly exists on Uranus and Neptune but has been frozen out because of the extremely low temperatures. Water probably exists as ice beneath the atmospheres of Jupiter, Saturn, Uranus, and Neptune. The present composition of the atmospheres of the outer planets greatly resembles the presumed primitive composition of the atmospheres of the terrestrial planets. Consequently, prebiological organic syntheses which occurred on the ancient Earth may be occurring today in the outer planets.

Radio noise from the planet Jupiter (Burke and Franklin, 1958) appears to originate primarily in the region of the Great Red Spot. This radiation, according to one theory, has been explained as arising from atmospheric electrical discharge on Jupiter. If this is indeed the case, then there can be little doubt that large organic molecules must be produced in the atmosphere of the planet. Ultraviolet radiation from the Sun may also be active in producing such molecular species. However, the abundance of ammonia rather than water on Jupiter requires that new attention be focused on biochemical systems in which ammonia rather than water is the solvent.

2. <u>Need for New Data</u>.

Only a small number of observational details of a few of the planets have been touched upon, but these should serve to indicate the extremely great need for the extension of planetary studies. Additionally, new approaches to these problems must be devised; new instrumentation must be designed to aid in their solution.

As one new approach to the question of large organic molecules in the Solar System we call attention to the need for adequate chemical and physical analysis of a significant sample of meteorites, particularly those of the stone variety. Preliminary results (Calvin, 1959) indicate that very large, rather complex, organic molecules exist in some meteorites of the carbonaceous chondrite variety.

3. <u>The Earth as a Control and Test Source</u>.

Nowhere in the literature is there adequate information on the microbiological profile of the Earth's atmosphere. There is available no information on positional or seasonal variations of such a profile. Instrumentation to permit earth sampling to determine microorganism content should proceed at once. Data from high-altitude balloons, high-flying aircraft, and rockets should be considered. The profile derived should be of high resolution in the sense that it describes the height distribution of each kind of organism, not all types taken together.

We should also consider balloons, high-flying aircraft, and rockets for preliminary flight testing of any device designed to detect life or organic molecules on other planets.

4. Extra-Solar System Objects.

As a final item under the heading of observations made from the surface of the Earth, we mention a high-risk, high-return project that should not be lost from sight: the detection of high-intelligence life on extra-Solar System planets by radio signals. The probability of such detection is obviously very minute, but if detection were achieved, the results would have the farthest-reaching consequences. Primarily, we believe that support should be given to radioastronomy to make possible construction of enough large radio telescopes to permit the use of some of the total available observing time for such a project. (There are far too few telescopes available now to devote time to such a high-risk project.) We further believe that those large radio telescopes devoted to satellite or planetary probe tracking should be equipped to make extra-Solar System planetary observations when not in use for their primary purposes. Support should be given to development of high sensitivity receivers and, if we ourselves are ever to try to communicate, to development of very high power transmitters. Such development should not be charged completely to extra-Solar System investigations. Such equipment would also be of value for further radar exploration of the Solar System to investigate, for example, the distance scale, a problem of considerable importance in launching planetary probes. (Price et al., 1959)

B. Observations from Vehicles Outside much or all of the Earth's Atmosphere.

The atmosphere of the Earth provides a stringent limit on our ability to make many kinds of critical observations of the planets. Only certain wave-length ranges of the electromagnetic spectrum will pass through the atmosphere; turbulence and other effects cause unsteady telescopic images and blurr fine image details formed by the radiation that is transmitted.

1. Observations from Balloons and Airplanes.

High-flying balloons can provide a reasonably stable platform above the portion of the atmosphere responsible for "bad seeing," at least in the visible and near-visible portions of the spectrum. Observations with telescopes of moderate size (up to perhaps 36 inches aperture), made visually or photographically, can be of considerable value in improving our knowledge of planetary features, and should be tried. Polarization studies can be adequately carried out from such a balloon platform and should be made, probably photographically. Some start in spectroscopy and photometry can also be attempted, but the great forward strides will be achieved when the observations are made from outside the atmosphere.

Balloons will permit a good test of various optical devices to detect organic molecules from satellites and probes.

2. Observations from Earth Satellites.

Satellites outside the Earth's atmosphere will provide a great deal of basic planetary information. It is likely that high resolution telescopes will not be immediately available on satellites, and therefore observations will be limited to those involving the entire surface of a planet. However, from a vantage point outside the Earth's atmosphere we can, through spectroscopy, detect small amounts of O_2, O_3, H_2O, and other important molecules in planetary atmospheres. If altitude control is very accurate, it may be appropriate to attempt spectroscopic detection of gases in certain regions of the Moon's surface where activity has been suspected. As the geometrical resolving power increases, we ca can perhaps study portions of the planetary surfaces. Clearly, the basic physical data on the properties of the Earth, cosmic-ray intensities, and so forth, are of interest as important background material to the biologists interested in extraterrestrial life. Color pictures of the Earth as seen from a satellite would be of very considerable interest to the planetary astronomer.

The satellite could provide excellent tests of apparatus designed to detect life on other planets through observations made from planetary probes.

3. Observations from Probes.

Probes to the planets and to the Moon offer the greatest possibilities to the planetary astronomer and the astrobiologist. With a close approach (but not a landing) the resolution of the planetary surface becomes great, and many different types of studies should be possible. In the case of Venus, temperature determination and atmospheric studies by spcetroscopy should have highest priority. Penetration to the surface will require that microwaves of perhaps several centimeters' length be employed.

The highest priority for biological observations of Mars made from a non-landing probe should be given to spectrographic observations in the infrared to detect major chemical bonds of organic molecules. Important spectral lines of C-H, N-H, O-H, and C=O lie in the range 3 to 7 microns and should be looked for.

Space probes offer exceedingly interesting possibilities for investigating the physical and chemical characteristics as well as velocity distribution of interplanetary particles. Direct probe contact may be used in the process of investigations; the particle properties may be studied as a function of position in the Solar System. Such investigations could lead to important conclusions in regard to the existence of interplanetary organic material and the motion of such material throughout the system. They would also provide data on the operation of the Paynting-Robertson effect as well as the influence of solar corpuscular and ultraviolet radiation on the particles.

To both the astronomer and astrobiologist determination of the chemical composition and physical structure of a comet by probe contact offers possibilities of similar great interest, particularly since such bodies (if long-period comets are chosen for the experiments) permit examination of material representative of the outermost regions of the Solar System and even interstellar space.

Until samples of the lunar surface become available, information regarding its composition might be obtained from observations of solar X-rays scattered by the lunar surface. It is not clear whether such celestrial Debye-Scherer experiments would be feasible, but their possibility deserves investigation. It is part of the mission of this Panel to encourage the development of new methods which will facilitate the collection of evidence for the occurrence of extraterrestrial life. A partial list of principles and approaches is presented here which may aid in the construction of apparatus designed to detect organic matter or living organisms. For the purpose of this report analytical devices will be divided into (i) those which will operate in interplanetary space and planetary atmospheres, and (ii) those which will operate on and below planetary surfaces.

a Interplanetary Space and Planetary Atmosphere. The techniques for detection of organic particles in interplanetary space and in planetary atmosphere may in part be adapted from those which had been proposed for high-altitude detection of life on Earth.

(1) Measurements of Emission Spectra. Planetary probes may carry on their exterior a device for the heating of particles passing through it, so that the presence of carbon can be judged by the emission spectrum.

(2) Measurements of Electron Scattering. The scattering of an electron beam by particles passing through it may be used as the basis of an instrument which will give information on the frequency, mass, and nature of the particles.

(3) Continuous Sampling Devices. A modification of the apparatus described in section II.B.3 can be employed in the detection of organic matter in space. The occurrence of viable organisms in interplanetary space and in planetary atmospheres might be demonstrated by a further modification of this apparatus. A sterile adhesive-coated tape is drawn past a collecting window, sprayed with nutrient media, and passed over a phototube to detect any increase in its opacity with time.

b. Planetary Surface and Subsurface Samples.

(1) Measurement of Emission Spectra. An apparatus can be built which, after landing on a planet, will collect a small sample of surface material, heat it, and determine the emission of spectral lines indicative of carbon compounds. This device can also be adapted for the examination of subsurface samples if it is combined with geochemical exploration equipment.

(2) Chromatographic Separation of Planetary Soil Components. Existing automatic devices for the chromatographic analysis of mixtures, although bulky at present, could be miniaturized and adapted to the analysis of soluble components of planetary soil. The development of such an apparatus will be of equal importance in the geochemical exploration of planetary soil.

(3) Detection of Live Microorganisms. A device is presently under construction which upon impact on a planetary surface will draw atmospheric gas and surface dust through a number of selected sterile culture media (Vishniac, 1959). Changes in acidity or turbidity are telemetered. An additional culture vessel will contain only water and be seeded with a larger sample of planetary surface material. This experiment may allow extraterrestrial microorganisms to grow in a medium resembling their natural habitat.

III. Laboratory Work

The interpretation of data collected by terrestrial observatories and those which are and will be collected by space probes, as well as the planning of experiments, requires extensive basic work which can be carried out in earth-bound laboratories. Several sample topics are listed here.

A. Simulation of Present and Primitive Conditions.

1. Formation of Organic Matter.

Experiemnts on the formation of amino acids and other organic compounds under conditions resembling primitive terrestrial conditions should be extended to systems more closely resembling probable present and past environments on moons and planets other than Earth.

2. Microbial Physiclogy.

Understanding of the behavior of extraterrestrial microorganisms might be furthered by the observations of terrestrial microorganisms, under simulated nonterrestrial conditions.

3. Analogous Systems of Organic Chemistry.

The possible occurrence of living organisms in nonagueous environments should be considered. A better understanding of the organic chemistry of nonaqueous systems, especially liquid ammonia, will be needed.

B. Laboratory Work Related to Spectroscopic and Polarization Data.

Spectroscopic observations of other celestial bodies are among the most promising experimental methods for the detection of extraterrestrial life. However, the value of these observations is limited by our ability to interpret them. In the near future, reflection and absorption spectra of other solar system bodies in all regions of the electromagnetic spectrum will be come available. The degree of polarization of the reflected light will be available both as a function of frequency and of the angle between the incident and reflected light. These data can provide much information concerning the chemical composition and the physical properties of the materials convering the surfaces of Solar System bodies as well as the composition of their atmosphere, provided we have (1) a thorough theoretical understanding of reflection spectroscopy in relation to absorption and (2) a library of reflection spectra of various terrestrial materials. Likewise, information must be available regarding the polarization of light reflected from various surfaces. At the present time, very little of this information is available. A large amount of investigation in these areas is definitely needed immediately.

C. Monographs to be Published Under Committee Sponsorship.

1. "Organic Matter and the Moon" - Carl Sagan (completed)

2. "The Problem of Life on Mars" - Carl Sagan (in preparation)

3. "Organic Chemistry of Liquid Ammonia Systems"-Author to be chosen

4. "A Re-examination of the Cosmobiota Hypothesis"-Author to be chosen

5. "Current Theories on the Origin of the Solar System"-Author to be chosen

6. "Organic Molecules in Cometary, Interplanetary, and Interstellar Sources" - Author to be chosen.

NOT FOR PUBLICATION OR
PUBLICATION REFERENCE

IV. Conclusions and Recommendations.

A. Recommendation Regarding Sterilization of Space Probes.

This Panel recommends that during the period of initial exploration of any extraterrestrial body, the probability of landing one viable organism be kept below one in 10^6. Therefore, until more information is available on the nature and distribution of organic molecules and living organisms, no landing of animals or men should be attempted on the Moon or planets, especially where there exists appreciable possibility of hard landings. A program should be initiated for biological and chemical analysis of lunar and planetary surface and subsurface materials by instrumented, unmanned, sterilized, soft-landing probes.

B. Recommendation on International Agreement.

It is pointless for a single nation to sterilize its probes; therefore we urge the Executive Council to request the President of the National Academy of Sciences to initiate international negotiations on this matter.

C. Recommendation on Establishment of Institutes.

Research programs such as those proposed in this document depend to a considerable degree upon cooperative work by scientists from a number of fields - Biology, chemistry, physics, astronomy, geophysics. The new approaches to the study of the Solar System that are vital to progress can be achieved only through the cross-fertilization of ideas that will result when imaginative scientists from such a variety of disciplines work together on common problems. The Panel on Extraterrestrial Life encourages the formation of such cross-field groups with interests in the broad problems of extraterrestrial life and the Solar System. The Panel recommends that institutes for the study of the Solar System be established at several academic institutions having staff members with interests and high competence in the requisite fields. Adequate laboratory equipment and research personnel must be provided so that work can proceed at the most rapid rate possible. Groups at different institutions might concentrate on different aspects of the problem, though some overlap of activities is inevitable and, in the long run, may prove to be useful. The various groups and individuals working in the Solar System research should remain in close communication; provision should be made for frequent intergroup visits. Contract support for Solar System Institutes should be provided on a sufficiently long time scale so that an adequate degree of stability and continuity will be established from the beginning.

Much planetary observational research needs to be done; many new observational experiments will be proposed and new data required as a result of the investigations carried on in the Solar System Institute. At present, telescope time for planetary studies is not adequate for the work proposed, especially if large telescopic equipment is required. The Panel therefore recommends that an observing station should be established with telescopic and auxiliary equipment to be used for planetary studies. The operation of this Solar System Observatory, which would be built in a place chosen especially for its favorable observing conditions, would be the prime responsibility of one group, but its facilities must be available to all Solar System investigators.

D. Recommendation on Communications and Meetings.

At a future date Panel 2 may include in its functions the sponsorship of meetings which will deal with estraterrestrial life. Such meetings may either be held in conjunction with those of existing organizations, or may take the form of independent symposia or informal discussions as the occasion demands.

E. Recommendation on Evaluation of Research Proposals.

In accordance with its stated mission the members of Panel 2 are willing to aid, collectively or individually, in the evaluation of research proposals which deal with the biology of extraterrestrial organisms. Studies of terrestrial organisms concern Panel 2 only when they bear directly on the biology of extraterrestrial life.

REFERENCES CITED

Burke, B. F., and Franklin, K. L., 1955, J. Geophys. Res., 60:213.

Calvin, M., 1959, unpublished.

CETEX Reports, Science, 128:887, 1958; Nature, April 4, 1959.

Dollfus, A., 1957, Suppl. aux Annales d'Astrophysique, 4.

Halvorsen, H. O., 1958, Bacterial Spores.

Hollaender, A., 1955, Radiation Biology, vol 2, McGraw-Hill.

Kuiper, G. P., 1952, Atmospheres of the Earth and Planets, Chap. 12, U. Chicago Press

Lederberg, J., and Cowie, D. B., 1958, Science, 127:1473.

Miller, S. L., 1955, J. Am. Chem. Soc., 77:2351.

Oparin, A. I., 1957, the Origin of Life on the Earth, Academic Press.

Phillips, C. R., and Kaye, S., 1949, Am. J. Hygiene, 50:270.

Sagan, C., 1959, "Organic Matter and the Moon", to be published.

Schiaparelli, G. V., 1894, Smithsonian Inst. Rep., p. 113.

Sederholm, C., Weaver, H., and Sagan, C., 1959, unpublished.

Sinton, W. N., 1957, Astrophys. J. 126:231.

Urey, H. C., 1952, The Planets, Yale U. Press.

Vaucouleurs, G. de, 1953, Physics of the Planet Mars, Faber and Faber.

Vishniac, W. 1959, NASA Contract NSG 19-59.