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SPACE SCIENCE BOARD

Summary Report of
WESTEX
February 21, 1959 - September 26, 1959

(including selected reference material)

October 16, 1959

The following report is a brief summary of discussions and conclusions of four meetings of Westex in 1959: February 21, March 21, May 2-3, and September 26th. This committee adjourned sine die at its last meeting. It stands ready to renew its meetings whenever warranted by new business.

INTRODUCTION

Westex is a group of West Coast biologists interested in the biological exploration of the planets.[1] The aggregation of many biochemists and microbiologists on the West Coast make the San Francisco area a convenient meeting place for a regional group, saving the trouble and expense of many people's travel. This group informally complements a similar one centered at the Massachusetts Institute of Technology whose report has been circulated as SSB-93.

Westex was originally convened February 21, 1959, upon the request of Dr. Bruno Rossi to advise him and the Board on the problem of contamination of extraterrestrial targets of space exploration. This meeting was under some pressure to report[2] prior to the meeting of Cetex[3] and Cospar at The Hague on March 9-11. However, its recommendations were reviewed in great detail at subsequent meetings and were unanimously and forcefully reaffirmed.[4] The committee was also requested (and is, of course, intrinsically inclined) to review the constructive aspects of research in exobiology (viz. the biology of the exosphere, the space beyond the earth's atmosphere). "Space Biology" often connotes life-support research in connection with man-in-space and with this the influence of space craft environments on man and other forms of terrestrial life. This area is now under comprehensive review by the Armed Forces-NRC Committee on Bio-Astronautics and we have not dealt with it at all except as it bears on the ecology of the planetary targets.

The term planet used in this report also includes the moon and the satellites of other primary planets. By implication we will usually be referring to the <u>other</u> planets excluding earth.

Some aspects of this report should be elaborated further, for example in contributions to "Science in Space."

SIGNIFICANCE OF EXOBIOLOGICAL RESEARCH

The detection and analysis of planetary life is one of the major challenges of contemporary science and should be pre-eminent among the objectives of our space research programs. Our immediate concern would be to clarify the evolution of life as we now know it on earth.[5] More profoundly, biology unlike physics and chemistry has been an earth-bound science. Twenty-five centuries of scientific astronomy have expanded our conception of the universe with a profound impact on all human culture, including the physical sciences. <u>Matter</u> and <u>energy</u> aspire to be universal concepts; <u>life</u> in contemporary science still means <u>terrestrial life</u>.

THEORETICAL POSSIBILITIES AND PRESENT EVIDENCE FOR PLANETARY LIFE

A detailed exposition of theoretical biology could warrantably lead to far flung speculations on the essential features that characterize living systems. Theoretical and experimental work of recent years has dispelled many of the obstacles to our understanding of the transition from inorganic to living matter.[13] We consider that this will eventually be possible in the laboratory; meanwhile, a study of life in totally independent evolutionary systems may give some invaluable leads. A priori, we believe it to be highly probable that life will evolve spontaneously if concentrations of diverse organic materials are maintained for intervals $\sim 10^9$ years in temperate environments. The consequence might be life whose chemistry is not necessarily at all like our own. Such speculations should by no means be discouraged. However, it is essential to establish a pragmatic starting point for the design of experimental space flights. For the moment, and until such time as these investigations are rewarded or proven futile, we should confine our studies to living systems sharing two basic attributes with terrestrial life: the use of water as the primary solvent for biochemical interaction and the use of polymers based on carbon as structural and catalytic components. The atoms H, C, O, and N, from which water and other biochemicals are formed are so nearly universal in their distribution that the limiting parameter in a planetary environment will, as a rule, be its temperature. Living forms, which are based on the co-operation of complex molecules cannot survive at temperatures at which these polymers dissociate. Life can survive in a dormant state in the absence of water but requires this solvent for its evolution and activity. Radiation fields of sufficient intensity will be equivalent to high temperatures in the dissociation of organic molecules provided they penetrate to all relevant strata of the target planet, which will not usually be the case. The criteria just enunciated have long made Mars and Venus the only probable foci for serious interest in planetary life since some water is known to exist on Mars and our ignorance of Venus does not preclude it. The moon, whose surface must be completely devoid of water, is of interest to the biologist, as it is to the planetologist primarily as a fossil by providing a potential source of the initial composition of the solar system from which life had evolved. More information on the sub-surface composition of the moon is needed before it can be completely dismissed as a totally waterless and lifeless object. The moon might be able to furnish evidence on the possible natural dissemination of interplanetary life through space. The proximity of the moon to the earth, and the consequent density of traffic to it, may make it difficult to sustain a conservative program but strenuous efforts should be made to preserve its initial features for the benefit of the many sciences which have an interest in them.

The question of planetary life has perhaps been disreputable because of extravagant claims made by enthusiastic astronomers in the past. At the present time, as the Board already knows, the main evidence which bears directly on exobiology is Sinton's infrared study of Mars.[6] He has described bands in the reflection spectrum of Martian regions which would correspond to absorption by organic molecules, for example formaldehyde or cellulose. Few spectroscopists would be willing to insist that these bands could not be produced by any minerals although we have not been able to locate an explicit alternative. A more serious concern is whether the absorption bands, even if of organic molecules, are evidence of biochemical rather than inorganic synthesis. The surfaces of the major planets are undoubtedly too cold for the maintenance of liquid water anywhere and life of terrestrial types is thereby precluded. However, a solvent mixture of NH_3, CH_4, and H_2 which would prevail on Jupiter gives us the most provocative alternative to an aqueous system of life. In any case the impact of solar radiation on a planet so largely composed of H, C, N, and O will eventually be of great interest for our understanding of the inanimate synthesis of organic compounds.

The negligible quantity of oxygen in the Martian atmosphere has sometimes been invoked to argue that active animal life cannot exist there. While oxygen may allow for a more efficient metabolism of terrestrial nutrients, the biochemical adaptations already exhibited by terrestrial micro-organisms suggest that it would be incautious to insist on any conclusions at all on this point. For the same reason the prevalence of gases that would be toxic to man is of no consequence whatsoever in precluding forms of life that might well be adapted to them.

The chemical constitution of planetary life is far more important than its outward appearance. For fundamental studies the existence of the most "primitive" micro-organisms on Mars would be almost as consequential as the occurrence of the most highly evolved types. The most pervasive feature of terrestrial life is the nucleic acid molecule whose accurate self replication is the basis of heredity and of organic individuality. No less striking is the distribution of protein composed of a basic set of twenty particular amino acids. If we could ask just <u>one</u> question of life on a planet it would be whether it was based on the same system of nucleic acid and protein as we know on earth. But we cannot ignore such fundamental questions as whether intelligent life of any kind had evolved and whether the planetary forms have the same organization into cellular units. Finally it will be of no small interest to learn the details of the adaptations in chemistry and in outward form which planetary organisms may have evolved as a specific adaptation to their own peculiar environments.

METHODS OF INVESTIGATION

Observations from Earth

Models of planetary systems. Some of the fundamental gaps in our general scientific information which would be relevant to planetary research have been stressed by various authors in

Science in Space. Here we have already noted the lack of sufficiently broad spectroscopic data on reflections from various minerals to be sure of a final evaluation of Sinton's experiments.[7] Fortunately, Calvin and his colleagues have undertaken an intensive program of infrared analysis much of which will be an important back-up to space probe experiments. The Committee feels that these verifications are of very great importance and urges all possible support for Dr. Calvin's program. It is probable that surveys similar to Sinton's can be profitably extended and particularly with the help of balloon-mounted telescopes. Likewise, it would be very helpful to have available all possible information on the appearance of the earth from moderate altitudes at various wave-lengths. It seems certain that the Air Force must have collected considerable information along these lines and its release would be of great scientific value.

Members of the Board have also commented on the value of meteorites as samples of interplanetary matter. The existence of carbonaceous compounds in meteorites (Mueller) is almost always overlooked in summaries of their chemical composition.[8]

One of the most useful instruments for the study of planetary chemistry and biology would be the satellite telescope. We are not certain whether its technical problems are likely to be solved before or after probes are sent to the vicinity of the planets. Planetary investigation should not be overlooked in the design and mission-analysis of the satellite telescope.

VICINAL PROBES

The Committee has pondered the question whether it would be possible to collect convincing evidence of the habitation of Earth from a satellite 200 miles away. It is difficult to give a definite answer to this question without more information on color and infrared photography of the earth by high flying aircraft. On the whole, we were rather skeptical that a decisive answer to this question would be possible, except for large scale products of human culture (cities, roads, rockets). However, such a satellite should be able to improve considerably on the approach used by Sinton, namely rough chemical analysis of the surface by infrared. The vicinal probe will, however, contribute important information along these lines, and should be designed as a back-up to soft landings in the event that guidance errors limit the distance of approach. The chemistry of the planetary atmospheres is of sufficient importance that the Committee suggests a careful study be made of the relative values of early planetary probes in comparison with the lunar missions which have been given earlier priority according to present scheduling.

Planet Fall (Landing) Experiments. The Committee could make no constructive suggestions for experiments involving hard landing. Possibly experience from similar trials on the moon may justify a reconsideration of whether a useful photograph at low altitude might be made in the course of such a mission. On the other hand, the atmosphere of Mars may permit relatively soft landings by the use of atmospheric braking with the least cost in retro-rocket work. The Committee urges strenuously that all possible information be collected by instrumented landings before any effort is made to collect samples and return them to the earth and particularly before manned landings are designed. In principle it should be possible to develop instrumentation to conduct any program of biochemical investigation.

In practise, such instrumentation does not exist at the present time. An urgent requirement for all aspects of planetary science is the development of instrumentation for the automatic gathering of surface and cored samples and their subsequent chemical analysis. Lightweight mass spectrometers as are already being developed for atmospheric analysis represent an important advance; the same instruments might be profitably adapted as the terminal sensors for systems of molecular-analytical chemistry. For example, the mass spectrography of gases emitted from samples subjected to specific chemical reagents, or to controlled heating, would give substantial information on the composition of relatively complex materials. Optical, and especially infra-red spectroscopy, should be amenable to similar adaptation.

The time required to develop these instruments is long enough that they will have to be attended to promptly to be ready in time for the corresponding vehicles. Automatic chemical analysis has been the subject of a recent symposium,[9] devoted mainly to applications in the clinical laboratory: the experience in these developments might be useful for our particular requirements.

Similar, even simpler instruments, can be designed to culture possible micro-organisms, signalling information of the growth or metabolisms of inocula from dust fallout or other samples. (Dr. Wolf Vishniac, of Yale University, is engaged in the actual construction of a prototype with the aim, in part, of classifying the details of possible designs and of assessing the difficulties of a ruggedized one.) There can be little doubt that micro-organisms will occur in any habitat capable of supporting any form of life. However, we have no prior knowledge of the nutritional requirements and metabolic effects of exobial forms though some plausible inferences would follow better knowledge of their habitats. We could therefore have no way of assuring the suitability of any culture medium used in the assay. (On an arid planet like Mars, however, water may well prove to be a limiting factor, and a sufficient 'nutrient' to elicit obvious vital response from a sample of soil. Further, glycine is an attractive candidate as a nutrient: it is the simplest amino acid, and one of the simplest compounds of C, O, N and H; it is a universal constituent of terrestrial proteins, and an important metabolite in the biosynthesis of other key compounds; it is the most likely (and first identified) product of photochemical synthesis from hydrogenous atmospheres (H_2O; NH_3; CH_4).)

Perhaps the chief objection to a simple micro-culture experiment is its limited heuristic value: A quite elaborate series of controls might be needed to lend conviction to a pulse on a tracing as evidence of planetary life. In addition, we cannot gainsay more organized forms, e.g., vegetation which would be recognizable as living by their visual appearance. An early picture of the planetary surface is a compelling entrant for the first missions in any case. We have therefore concluded that the first priority in exobiological study might be to a vidicon survey.

For more precise study, the vidicon may prove to be the most useful of sensors -- if, as we are assured, communications bandwidths are likely to keep pace with the technical requirements. For example, an optical microscope input to the vidicon could give the most convincing evidence of micro-organisms, both in situ, and in the effluent from a culture vessel. Furthermore, the use of travelling films should furnish a convenient method of carrying specimens through the object plane of a fixed-focus microscope, and also of subjecting the specimens to quite informative procedures of cytochemical analysis. (Thus, the alteration of an object-particle by the enzyme deoxyribonuclease, as observed with the microscope, would be a simple, sensitive, easily controlled, and compelling test for the presence of DNA.) To be of most use, the microscope should be operable to several wavelengths, particularly in the UV around 2600 Å, as well as the visible. It would thus be usable as a microspectrophotometer, with applications for inorganic chemical analysis too.

An important factor in this priority judgment is the present commercial availability of an analogous instrument, a television microscope. We urgently recommend that the Board investigate the means for the prompt adaptation of this type of instrument for planetary science.

CONSERVATION OF SCIENTIFIC RESOURCES

Contamination of extraterrestrial objects. Previous minutes from this committee have stressed the dangers of biological contamination, especially of Mars and Venus.[2] We continue to reaffirm the necessity of maintaining strenuous precautions against such contamination. One element in such a policy is obviously the collection of the most possible information from safe (i.e. telescopic or vicinal) approaches before landings are attempted. The more information we have about the planetary habitat, the better we can assess the actual hazards entailed by a landing and the precautions that should be taken. On the basis of present information, we would urge that a tolerance level 10^{-6} be adopted as the residual, composite risk of depositing a viable micro-organism on Mars or Venus.[10] We also believe that this is a plausible objective for an energetic program of payload decontamination, which had been recommended in further detail by an ad hoc committee sponsored by the Board.

The liability of the Moon to biological contamination is more controversial. Solar UV and the proton flux would rapidly disinfect any exposed objects. However, it is difficult to make any categorical statements about deeper and protected sites (cf. Galileo)[12] and it would be rash to disregard the conservation of biological interests there before we have the benefit of closer study. There has been considerable discussion of the consequences of hard landings, which we are unable to resolve. In particular, the entire missile might be heated by impact, and the mass confined to one site; alternatively, fragments might be dissipated over a large and uncontrollable area. If this issue can be decisively resolved, it should be taken into account in efforts to meet the recommendation that lunar missions should be cleaned and decontaminated according to the best technique available at the time, with a view to reducing the residual risk per missile to a value 10^{-1}. This suggestion is, of course, also subject to revision in response to more information.

We applaud the respect for these considerations on the part of the USSR in the light of Academician Topchiev's announcement that Lunik-II had been decontaminated. We would, further, welcome an opportunity to discuss optimum techniques for decontaminating further missions conducted both by the USSR and the US.

The survival of micro-organisms in transit through space would be severely limited by their exposure to solar radiation, both the ultraviolet and the proton-corpuscular components of which would rapidly inactivate any exposed organisms.[14] However, these radiations have a very limited penetration, and they will have a negligible effect on organisms shielded within a spacecraft or imbedded in a meteorite. More penetrating radiations, e.g. cosmic rays and solar x-rays will inactivate micro-organisms only very slowly, notwithstanding their potential hazard to more sensitive, higher forms of life.

The high vacuum of free space, far from being inimical, may help in the preservation of micro-organisms. Many stocks of bacteria and fungi are routinely preserved by drying them and keeping them at reasonably low pressures. However, there has been little or no effort to test the viability of bacterial spores at very low pressures (say $\leq 10^{-9}$ atmospheres), and it has been suggested that these may result in the distillation of vital components of the cells. This experiment might be conducted in a recoverable satellite, or with some difficulty, in the laboratory. Dr. Harlyn Halvorson's proposals in this direction warrant the most sympathetic consideration, since this question is of considerable importance both for fundamental biology and its applications in space research.

IDENTIFICATION OF MISSILE COMPONENTS

Since the fate of an impacting vehicle is in some doubt, planetary expeditions may eventually discover multilated fragments of uncertain origin. These doubts might be mitigated by some system of labelling the payloads. At the least, careful records should be kept of the precise composition of all planetfalls, preferably with the retention of exact replicas of the components. (Some months ago, some unusual iron meteorites were distinguised from artefacts only after laborious study.)

CONTAMINATION OF THE EARTH

If active life exists on the planets, this raises the possibility of the introduction of new kinds of organisms to the Earth. Without more explicit information, it is difficult to assess the practical consequences of such "back-contamination." It is most unlikely that such organisms would be pathogenic for man, since the instigation of disease and the spread from person to person require many fine and long-evolved adaptations on the part of the parasite. (On the other hand, we will not have had an opportunity to evolve any specific defenses against such potential parasites.) A more likely risk is that of an ecological nuisance which would interfere with our easy occupation and exploitation of the earth's surface. Many of the antibiotics produced by soil micro-organisms are seemingly accidental byproducts of their normal metabolism; new organisms, with unique metabolic pathways might produce antibiotics which interfere in the normal cycles for carbon and nitrogen on which our agricultural (and vital) economy depends. One could, for example, visualize organisms that, having evolved electron-transfer systems other than the cytochromes, might produce carbon monoxide or nitrous oxide in large amounts. We know of many unhappy examples of biological competition from the introduction of new organisms into fresh niches -- e.g. many insect pests in the US; rabbits and prickly pear in Australia, smallpox into the New World, and syphilis into Europe. Even the relatively limited damage of these incidents should not be duplicated as a byproduct of space research.

It therefore follows that the reimportation of spacecraft that have entered the atmospheres or surfaces of the other planets* should be stringently interdicted until exhaustive biological studies have

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*This stricture probably can be relaxed for the Moon. Provided only that our general conceptions of the Moon's surface are verified by early probes, indigenous life cannot possibly have evolved independently on the surface; if any organsims are disseminated in meteorites, these will reach the earth in any case. However, the caution should be kept in mind if any chemically exceptional features are found in lunar investigation.

been made by remote methods. These studies, we may hope, can furnish the information needed to make a reasonable estimate of the hazards entailed by lifting the quarantine. Since manned space-flight implies return trips, exobiological study must be emphasized as a prelude to this mission.

Finally, it may be remarked that the task of evaluating the potential hazard of a planetary biota will be multiplied if this has to be isolated from organisms inadvertently transferred from earth.

CO-OPERATION WITH OTHER NATIONS

Exobiological research is a common aspiration of all human culture; likewise, its successful prosecution requires the best use of available talent and instrumentation. Furthermore, the hazards of contamination of planetary targets, and even of the earth itself, can best be met by the fullest co-operation of all nations undertaking space research. These considerations are underlined by the spectacular success, in recent weeks, of the USSR in its lunar probes. We therefore urge that special stress be given to exobiology as an area for discussion of international co-operation. To this end, the members of Westex would heartily endorse an invitation to their opposite numbers in the USSR to meet together in the same spirit that has motivated our own meetings thus far. As a practical alternative, the forthcoming COSPAR meeting at Nice (January 1960) should afford an excellent opportunity for such discussions and we hope that this subject will be programmed, and that the USSR be encouraged as cordially as possible to send its representatives. We continue to urge President Bronk to use the good offices of the National Academy of Sciences to the fullest possible extent to elicit such co-operation.

Several observers have commented that it would be a striking gesture for scientific co-operation if USSR boosters, demonstrably the most technically advanced, could be made available for scientific missions that have been planned and instrumented through such international efforts. There may be some understandable reluctance in the US as well as the USSR to undertake such a co-operation. Some of us, at least, believe it cannot hurt our national prestige if we accept the obvious realities of the situation in a mature and constructive way, even while pursuing technological parity in vehicular capabilities.

References

1. The Westex Committee has consisted of the following members: (per attached sheet) Calvin, Davies, Horowitz, Marr, Mazia, Novick, Lederberg, Stent, Van Niel and Weaver.

   We have also enjoyed discussions with: Sagan, Sinton, Thomas, Bracewell, Urey.

2. Reports of Westex-1. (Copy enclosed)

3. Cetex-2 report (March 1959)

4. Westex-1D (see ref. 2)

5. Horowitz, N., 1959 Space Research and the problem of the origin of life. (Westex 1E)

6. Sinton, W. M., 1957, Spectroscopic evidence for vegetation on Mars. Astrophys. J. 126: 231-239. Also, mss, in press and paper presented at AAAS, Gainesville, Fla., Dec. 1958.

7. The development of color centers in otherwise transparent crystals as a result of heavy irradiation introduces a complication not easily controlled.

8. Lederberg, J. 1958 "Moondust" Science, 127: 1473-1475 (copy with note p. 1474 enclosed)

9. Conference on automatic analysis. New York Academy of Sciences (Nov. 12-14, 1959) (copy enclosed)

10. Davies, R. W. and Comuntzis, M. G., 1959, The sterilization of space vehicles to prevent extraterrestrial biological contamination. 10th Intl. Astronautics Cong., London, Proc., In Press. (JPL External Publ. 698.)

11. SSB-109 - Space Science Board Recommendation on Space Probe Sterilization

12. Galileo, G., 1610 - see attached quotation.

13. Oparin, A.I., 1957, The origin of life on the earth, 3rd ed. Academic Press, N.Y.; J. H. Rush, 1957, The dawn of life, Hanover House, N.Y. (I would especially recommend Rush's book for Board members and other scientists who are not biologists, as a resume of current thinking on the mechanisms of living origins. S. L. Miller, H. C. Urey, Organic Compound Synthesis on the Primitive Earth, S. L. Miller, H. C. Urey, Science, 130, p. 245-251.

14. Sagan, C., 1959, Organic matter and the moon. (Copy enclosed.) Sagan intends to give this paper (at H. J. Muller's invitation) at the NAS meeting in Bloomington in November. This is a preliminary version; some changes have been indicated, and he would invite comments. I would raise the possibility of printing this in toto, or asking for an abstract, as an appendix.

<u>Other exhibits</u> (for possible use in appendix)

15. Calvin, M. and others 1959, Bio-Astronautics Panel No. 2 Report. Dr. Calvin is quite agreeable to the republication of this report.

16. Sagan, C., 1959, Venus as a planet of possible biological interest. Report prepared under JPL auspices for use by SSB and by Bio-Astronautics Committee.
(This also is subject to final revision -- the enclosed is my only copy: it would be a service if, in any case, this could be duplicated for review by Westex and SSB.)

Ref. 1

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WESTERN GROUP ON PLANETARY BIOLOGY

Discussion, February 21, 1959

Stanford University

Stanford, California

Present were:

University of California, Berkeley:

Calvin (Chemistry)
Mazia (Zoology)
Stanier (Bacteriology)
Stent (Virology)
Weaver (Astronomy)

NASA-JPL

Hibbs
Davies

Stanford University

Krauskopf (Geochemistry)
*Lederberg (Genetics)
van Niel (Microbiology)

*Recorder

University of California, Davis:

Marr (Bacteriology)

University of Oregon:

Novick (Biophysics)

California Institute of Technology

Horowitz (Biology)

Stanford Research Institute

Kamphoefner (Control Systems)

AGENDA

The appendices were distributed as working papers prior to the meeting. The MIT discussions (December 4 and December 19-20, 1958) were not available in time to be distributed to everyone in advance and will be reviewed at our next meeting, scheduled for March 21, 1959, at the JPL, Pasadena.

In view of the imminence of the CETEX meeting (March 9-10, 1959) and Pioneer IV (launched March 2, 1959), we focused attention on specific problems of celestial contamination and the decontamination of moonshots, deferring the more general aspects of a constructive program.

Hibbs outlined the dimensions of the Pioneer payload (since published in the press) and the procedure now being followed. Important features are: (1) a protective outer casing, which is shed at about 70 miles altitude; this is not airtight; (2) a scrubdown of the outer surface of the payload with absolute alcohol, followed by UV; (3) the lower part of the missile is not exposed to solar radiation at any time; (4) there was no information on the microbial status of the interior of the payload.

Hibbs also indicated a general timetable of planetary probes, which include two problematical probes at Venus in June, 1959, and several further attempts at the moon and at Mars in late 1959 and throughout 1960. While it is not highly probable that these probes will impact, this cannot be excluded.

DISCUSSION

The general principles of the CETEX report (Science, October 17, 1958) and of Appendix B were adopted with the following additions, observations, reinforcements, and revisions:

1. It would be a scientific catastrophe to make the cosmic blunder of uncontrolled contamination of another planet by terrestrial microorganisms. Our present knowledge of the planets Mars and Venus does not exclude the possibility of accomplishing this by depositing a single bacterium or spore from a probe.

2. The detection and identification of life on other planets ranks next to the recreation of terrestrial life as the outstanding challenge to contemporary biological science. We now have an increasingly plausible picture of the steps whereby life evolved on earth. This supports a strong expectation of parallel developments elsewhere, wherever the availability of carbon compounds (which are universal), water or other solvents, and a suitable temperature range are compatible with the evolution of chemical complexity. The unspoiled state of the surfaces of the other planets may be the only means ever available to human science, and certainly the only one for many years to come, whereby these speculations can be tested by explicit observation. Planetary chemistry and biology are therefore irreplaceable sources of knowledge for the origin and essential features of life on earth. Uncontrolled contamination might destroy most of the values of this experimental approach.

(Dr. Horowitz will have prepared a more detailed exposition of this theme.)

3. Planetary biology must also rank very high in the scientific and social objectives of space research in general. The political, moral, legal, and economic consequences of premature contamination of celestial objects can hardly be estimated on the basis of present knowledge.

4. Even if these cautions constituted a serious obstacle to the achievement of other scientific aims, they would still have to

be credited, since biological missteps would do irreversible harm, while misjudgments in the physical sciences, though costly and exasperating, might still be remediable. However, we believe that it will be possible to incorporate biological precautions into the space program in a constructive way that should not impair other serious scientific aims. To do this will require, however, an earnest recognition of the importance of the problem and an intensive program of research on a wide front. This will be done in time only by awakening the interests of a number of alert biologists throughout the world.

5. The minimum condition for biological security would be the application of our full knowledge of microbial control throughout the design and assembly of the probes and terminal sterilization at launching (and atmospheric transit?). Above all, this must be accompanied by control evidence of the total efficacy of these procedures in the circumstances of their application. The development of methods of gaseous fumigation, especially with ethylene oxide, makes this aim a realistic one, so that the microbial control should not add appreciably to the total effort involved in the space research program, nor, given vigorous support, should it necessitate serious delays in the firing schedules.

Several laboratories are already involved in problems of large-scale sterilization, and their technical expertness should be exploited as far as possible.

6. We require additional information on the microbiology of missile components (e.g., are lyophilized bacteria trapped and preserved in vacuum tubes?), the launching site, and the atmospheric profile. Need, and if so can, a presterilized payload be effectively protected from atmospheric contamination? The distribution of microbes and biochemicals at high altitude would also be important knowledge for evaluating possible mechanisms of escape and infall and of photochemical synthesis of biochemically interesting compounds (e.g., what is the source of organic nitrogen in rainwater?).

7. Present methods of surface decontamination (as outlined by Hibbs) are too ineffective to be commensurate with the needs. However, they do at least contribute to the cleanliness of the payload and can, perhaps, be justified as a token effort. The contents of the payload are almost certainly more heavily contaminated and more effectively protected from sterilizing radiations. Of the methods discussed, including ionizing radiations, gaseous fumigation appears to be the most likely; however, some provision must be made for effective penetration of the fumigant, e.g., into tube sockets and screw holes, perhaps together with the use of self-sterilizing materials, lubricants, and padding and the presterilization of sealed assemblies.

8. More information is needed on the effects of missile impact. The supposition (Cetex -1) that fallout will be localized owing to the rarity of the atmosphere is unconvincing, and perhaps already contradicted by the well-known "lunar rays" which can extend for a thousand kilometers. A more likely event is the dissipation of kinetic energy as heat to very high temperatures, but more data and calculations are needed to show how much of the missile would be dispersed rather than heated (see Appendix C).

9. Although there are many telling arguments against survival of spores and their transit from one planet to another, many more or less convincing suggestions can be made for the expulsion and protection of an occasional particle. We therefore concluded that we could not decisively exclude panspermia on a priori arguments. Again more experiments are needed on the fate of spores and other particles in solar radiation fields, and more data are needed on electric or other forces in the upper atmosphere that might function in expulsion.

10. Although the moon is generally agreed to have no appreciable atmosphere, and therefore also no surface hydrosphere, Alter and Koryzev's recent observations on gaseous emissions at Alphonsus again raise the question of local sources of gases and, in turn, the possibility of interior sources of moisture. As long as there is any possibility of internal moisture, the moon may also be a sensitive target, and at least this point should be settled decisively before concluding otherwise. It is likewise difficult to preclude entirely the evolution of another form of life on the moon until we know more of its surface chemistry and particularly what may lie deep in its fissures.

11. For these reasons--namely, the remote possibilities of evidence for panspermia, of persistence of moisture, and of probiotic or biotic evolution--we suggest that the moon also be considered as a potentially sensitive target and that contaminating residues be kept to a reasonable minimum. However, it is most unlikely that terrestrial organisms could proliferate, and therefore the moon should be a legitimate testing ground for missiles on which microbial control is being developed.

12. Even if it is incapable of supporting terrestrial life, the moon is still an object of great biochemical interest, and total contamination should again be minimized. The most easily detected particle of terrestrial provenance would be a viable spore, which speaks for a contamination load of at most 10^8 per missile. This should easily be obtained. Ultimately, our biochemical techniques may be capable of detecting a similar incidence of inviable particles, and this tolerance should be a guide to the upper limits of microbial contamination before sterilization, subject to more information under heading 8. It was pointed out that "clean" supplies of distilled water may be able

to support bacteria to levels of 10^6 of 10^7 per milliliter if left standing, but special precautions should allow for cleaning to higher standards.

13. The molecular inventory of missile deposits should be of inestimable value in identifying suspicious objects found in later explorations. Some thought might be given to the consistent use of characteristic alloys as labels of terrestrial origin of metallic components and of a limited group of plastics to do the same for organic polymers.

14. We need to develop more effective channels of communication:

   a. With Russion scientists, especially biologists (see Appendix C);

   b. Between the space research program and U. S. Biologists with respect to missile programming and technology, and also scientific information on the solar system.

We have already recorded our urgent request to encourage Russian representation on CETEX. In addition, it would help to identify those Russian scientists most likely to be thinking about problems of planetary biology. Can we get translations or at least abstracts of papers being published in the Russian journal <u>Astrobiology</u>?

15. We recommend the continuation of our discussions and request prior assurance of funds from NAS or NASA to assure the continuity of our meetings.

APPENDIX A

SUGGESTED AGENDA: DISCUSSION ON PLANETARY MICROBIOLOGY, FEBRUARY 21, 1959

A. 1. What is the significance for biology of the occurrence of life on other planets? (Most laymen will appreciate this, but some physical scientists, as well as biologists in fields not closely connected with evolution, might profit from a clear statement.)

2. What is the range of our expectations? (Since this question involves a definition of the conditions under which life can be expected to evolve and persist, and therefore of the meaning of the term "life," I would suggest leaving this for continued discussion in future meetings. It might be profitable for each of us to state his own preliminary views briefly for further reflection.)

3. What would constitute "contamination": (a) for a sterile, nonhabitable planet; (b) for a sterile habitable planet; (c) for an inhabited planet? (Habitable might mean either by extant terrestrial organisms or by an indigenous biota.)

4. Is it possible to assess the relative importance of biological and other scientific exploration? A rigorous policy to avoid contamination of, say, Mars might lead to substantial delays in planetary research and therefore encounter strong opposition from other groups.

B. 5. What specific information is most urgently needed for the formulation of policy: (a) as the best assessment of existing data, or (b) that might be obtained with the help of existing instrumentation and theory? (The physicists must be told what we need to know. I have put two questions already--the distribution of moisture on the moon and on other planets [see Hess, 1958] --and the possibility that any fragment of a missile can survive a hard landing without being heated quite hot.)

6. What would be the most effective machinery for further communication along these lines?

7. What information do we need on the organization of space research in the United States and elsewhere?

8. What would be the best approach to reaching common policy on planetary biology with the USSR? Official channels? Semi-official action through CETEX and COSPAR? Coordinated or independent private communication with Russian scientists? Which Russian scientists are most likely to be our opposite numbers?

C. 9. Moonshots are being planned and executed at this time. What immediate recommendations can be forwarded? By what means (and how long would it take) should a definitive policy be formulated? (Should rockets be sterilized?

If so, how best? Should hard landings be prescribed altogether? What about soft landings? What is a tolerable level of risk that a circumlunar-orbital mission deviate into moonfall? --Programming is likely to aim at this error to help insure a more "significant" result.--)

10. What would be the most constructive program for progressive approach to the moon (if an immediate hard landing is discouraged)?

D. 11. Mars and Venus will probably be programmed within the next one to five years. What cautionary policy do you recommend? How strenuous should it be, especially if preliminary "safe approaches" give negative results?

12. What constructive proposals can we make for progressive exploration, beginning with the safe approaches outlined in the Boston resume (observation from: the earth's surface, a satellite of earth, a satellite of the planet)? Can we design a sterile planetfall? What would be the most sensitive criterion (or series of criteria on various predicates) for planetary life? To illustrate, how would a "Martian" best determine that the earth was inhabited (apart from human activity): (a) from an orbit, say, 1,000 miles up; or (b) by an instrument weighing up to 30 pounds deposited on the earth's surface?

Ref. 2

APPENDIX B

CONTAMINATION OF A PLANETARY SURFACE BY INTERPLANETARY MISSILES

An interplanetary missile is equivalent to an artificial meteorite and is therefore unlikely to alter primitive surfaces except insofar as its composition uniquely reflects its terrestrial origin. The abundance of *atomic* species can be assessed so that it should be possible to obtain a consensus on tolerable levels of transport of, say, specific radioactive isotopes. We have much less basis for estimation of abundance of *molecular* species, especially large molecules and self-replicating particles. The problem is complicated by the ready interconversion of molecular species and especially under the catalytic mediation of either inorganic or living polymers.

As a general principle for the design of exploratory missiles, one might therefore argue that complex molecular species should be minimized in favor of elementary (*viz.* metallic) components which are already ubiquitous.

However, we cannot point to any important catalytic effect of the compounds used as industrial plastics, and in view of the possible unavoidability of carbonaceous rocket fuels, these molecules possibly cannot be excluded altogether. There may be some point to minimizing them and to maintaining a careful inventory of all substances deposited on extraterrestrial targets, at least until we have more complete information on the composition of the landing sites.

Molecular contamination can become significant when it reaches a level that we can hope to detect by analytical methods which either are now available or *ever* will be devised. We are not likely to be interested in infinitesimal changes over a background level. We should be interested in species of which the presence of one molecule on a planet might alter our conceptions of the uniqueness of life on the earth and the mechanism of its origin. Subjective estimates of the likelihood of finding such molecules (and by any argument this is very small for the moon) must be combined with the immensity of the consequences in evaluating the risks of exploration.

Three classes of celestial objects offer different expectations of present composition, with progressively greater risks of spoiling future research on extraterrestrial biology:

(1) *Planetoids and minor satellites*, owing especially to their redundancy and also to their homogeneity, negligible gravity, and total lack of atmosphere, must be the safest (if least interesting) targets. If guidance can meet the challenge, this would be an additional argument for programming, say, Deimos for the first demonstration of manned interplanetary flight. (The energetic and observational advantages are well known already.)

(2) *The moon* has intermediate gravity which precludes the retention of astable atmosphere, but it can still sweep out interplanetary particles. The size of the moon also allows for local singularities (e.g., deep, protected

fissures), continued seepage of internal materials to the surface, and sedimentary stratification, allowing some shielding from solar radiation.

It seems certain that there cannot be enough water anywhere on the moon to sustain the growth or spread of any terrestrial organisms. This premise is less certain now in view of Krzynev's claims and tolerances for contamination should be altered accordingly. The level of organic contamination will therefore remain at not more than the amount deposited and is certainly subject to substantial attrition by thermal, chemical, and photochemical decomposition. This factor might, however, be exaggerated by overemphasis on the unfavorable conditions prevailing at the outermost layer of the lunar surface.

To a first approximation, the tolerance should match the level we could ever hope to detect, or perhaps more realistically, to detect before precautions are relaxed under pressure of negative evidence. This is hard to predict. However, the moon's surface ~ 4 by 10^{13} m^2. The deposit of 10^{13} microorganisms would obviously be undesirable. But this would not deviate grossly from the probable level of, say, the remains in an ill-starred attempt at human landing, especially if failure involving, say, suffocation preceded a hard impact.

Present technology might hope to detect one microorganism per m^2 of surface. If we arbitrarily limit technical and scientific extensions to, say, 0.4 km^2, the corresponding tolerance would be 10^8 for certainty of confusion ($p=c^{-1}$) and 10^5 for $p=.001$ of confusion in any such sample of random surface.

It should be possible to maintain this level of sterility, viz. $\gg$ 105 per missile, by scrupulous cleanliness which would, in any case, be preferable to "sterile dirt" (see discussion below on chemical contamination). I would stress that this is a personal estimate of tolerance and that your group must weigh the consequences of its being too liberal against the other virtues of the experiment. I have some misgivings about the risk of a too hasty and too isolated judgment, but this seems the only tenable position in the face of national and international pressures for prompt and spectacular action. Otherwise, I would have thought it more prudent to base further plans on the findings from circumlunar satellites. If we really knew the parameters which underlie our assessments, we wouldn't need to send the device in the first place. The chemical attrition may, of course, be a decisive factor in forfending the hazard.

Soft landings may be less hazardous by concentrating a contaminating deposit in a small area, leaving others relatively cleaner. Gold has discussed large-scale movements (dust flow) that might occur even in the absence of an atmosphere. Hard impacts may well deposit particles of the missile randomly over the moon's surface, an especially disturbing possibility for a cushioned hard landing which would protect contaminants as well as instruments from evaporation.

I do not feel it should be necessary to defend the plausibility of the preoccurrence of microorganisms (or more likely molecular fragments) on the moon's surface. Arrhenius's arguments are not so implausible that they should be totally ignored, but I would rather plead our basic ignorance than an explicit mechanism such as panspermia.

APPENDIX C

PRELIMINARY REPORT: FORMAL RECOMMENDATIONS OF AN AD HOC COMMITTEE ON PLANETARY BIOLOGY, STANFORD, FEBRUARY 21, 1959

1. Our present knowledge of the planets Mars and Venus is compatible with the possibility both of an indigenous life and of the maintenance and rapid spread of terrestrial microorganisms. The premature introduction of terrestrial organisms as contaminants on planetary probes might so distort the biology of either planet as to constitute a scientific catastrophe of the worst order. We must measure the consequences by the considered conclusion that the investigation of life on other planets is the most sensitive to irremediable harm and among the most important of the scientific objectives of space research, and is an equally cogent problem in the whole context of contemporary biological theory. It would therefore be an irresponsible act of policy to program any mission having a significant chance of introducing a single viable organism to the surface of Mars or Venus until we have all necessary information to measure the consequences. As a practical measure to effect an orderly and safe program of investigation, projects should be preferred which allow of observations from safe distances. In addition, any missiles which might have any likelihood of a landing, intentional or accidental, should be subject to careful sterilization. The sterilization should consist not only of the best currently used methods of sterilization (perhaps fumigation by ethylene oxide gas) but of empirical controls, by microbiological study, on the effectiveness of the sterilization procedure. The application of sterilization procedures, together with the indicated controls, should be a minimum condition of any code of conduct to be formulated by CETEX.

2. The status of the moon as a biologically interesting target is considerably more doubtful than that of the planets. However, if there is any possibility of persistent moisture at any accessible level of the lunar crust, it may prove to be as amenable to some form of contamination as the planets. Accepting the traditional concept of the moon as anhydrous and therefore sterile with respect to active life, we still find two important considerations: (1) the role of the moon as a gravitational trap for interplanetary material; and (2) the extent of prebiotic organic synthesis that may be indicated on its surface. The likelihood of interplanetary dissemination of spores (panspermia) is rightly considered to be remote, but we are unable to exclude it beyond further consideration. In addition, while many processes incidental to the mission and its impact may destroy a large fraction of contaminating microorganisms, information presently available does not give us assurance of the certainty of their complete destruction. We therefore recommend that vigorous sterilization procedures continue to be applies to moonshots along the lines indicated for the planets. The introduction of the microbiological factor into design and fabrication of the moonshop packages may also give useful experience relative to the deeper probes.

3. In order to minimize chemical contamination of a kind that might confuse later investigators, we recommend that a careful "molecular inventory"

Ref. 2

should be made of each mission (perhaps together with the preservation of an actual replica of each package). Synthetic polymers are presumably unavoidable; they should always be used in place of substances of biological origin (e.g., casein glue). Finally, careful attention to overall cleanliness of the package is perhaps the most important factor in minimizing the contamination "noise" in the interest of later investigators.

4. Biologists have only recently begun to appreciate the urgency of devoting serious thought to problems of planetary biology. We recognize the validity of claims of other scientific groups and hope to generate constructive and decisive experiments at the earliest possible date, keeping in mind the novelty and subtlety of the problems facing us.

The study group considers it crucial to find channels of communication and cooperation with Soviet and other scientists for study and execution of experiments in planetary biology. It therefore requests that you forward to Dr. Bronk, as President of the National Academy of Sciences, the suggestion that urgent representations be made to the Academy of Sciences of the USSR:

a. To enlist their assistance in formulating a code of conduct in the CETEX discussions by sending a microbiologically informed delegation to this meeting.

b. To invite their cooperation in organizing an international scientific conference at the earliest possible date to discuss common objectives, exchange information, and review biological projects as the constructive counterpart for CETEX.

To avoid possible confusion with programs, such as "man-in-space" which may be identified with military objectives and the race for advantages therein, we suggest that the consideration of planetary biology be carefully dissociated in such discussions with Russian scientists.

We hope that this suggestion can be given Dr. Bronk's earliest attention if it is to have any practical effect.

APPENDIX D

COMMENTS ON CETEX-I REPORT, AS PUBLISHED IN *SCIENCE*, OCTOBER 17, 1958

1. The committee felt it would be difficult to place sufficient stress on the importance for theoretical biology of unimpeachable evidence on the status of life on other planets. We now have an increasingly plausible picture of the steps whereby life evolved on earth, so that we have strong expectations for parallel developments elsewhere, wherever the availability of carbon compounds (which must be universal), water or other solvents, and temperatures in a suitable range are compatible with the evolution of chemical complexity in organic (carboniferous) compounds. The unspoiled state of the surfaces of the other planets may be the only means available to the human species ever, and certainly for many years to come, whereby these speculations can be tested by explicit observation.

Laymen and other scientists may be expected to be equally strongly motivated by a fundamental curiosity as concerns the uniqueness of life in the universe to recognize planetary biology as one of the most fundamental issues in space exploration that will persist when most of the momentary pressures have been forgotten in the perspective of history.

If any errors of judgment are to be made, clearly they must be conservative ones. Would this generation of scientists ever be forgiven by its successors if it permitted the execution of a cosmic blunder that could be remotely anticipated? By their very nature, experimental missteps in biology may do irreversible harm; in the physical sciences they may lead at most to exasperation, delay, and waste.

On the whole, we believe it necessary and possible to formulate a program of space research that conserves objectives in biological science without impeding sober objectives in the physical sciences. Indeed, the two programs are not fundamentally separable.

2. The CETEX report is a clarifying document that does much to place the start of planetary biology and chemistry in reasonable perspective. We would, however, take exception to some particular points that warrant further discussion:

a. "Any contamination of the (moon) dust by space operations will be localized" owing to the low density of the atmosphere.

This premise is fundamental to a number of assurances concerning the safety of lunar probes, but can it be supported? No particle will reach the moon's surface with less than escape velocity. Any fragment which recoils, having dissipated half or less of its kinetic energy, will have sufficient velocity to orbit the moon. Residual energies of less than half will allow for parabolic trajectories to ranges approaching the whole perimeter. The absence of an atmosphere allows for the prompt dispersal of parts of the missile to any point on the moon's surface. This supposition is concordant with the widely accepted interpretation of the lunar rays, especially Tycho, precisely as the result of fallout from meteoritic infalls. These rays may extend for thousands of kilometers! (See Baldwin, The Face of the Moon, 1949.)

(A more cogent expectation is that any uncontrolled impact may result in the dissipation of most of the kinetic energy as heat. If this can be substantialted for lunar impacts, there would be no danger of biological contamination. However, it appears to be uncertain whether we could rely on impact-heat sterilization of the entire payload; indeed those fragments that were most widely dispersed might be expected to be heated the least, since they would have dissipated less of their infall energy on the impact. This question plainly has not been exhausted.)

Other means and assurances of localization of missile components must be found.

b. "Solar radiation would decompose biospores just as it decomposes cosmic dust. . . ."

This may be granted for exposed particles lying on a smooth, unprotected surface. The point of exception is obvious: The moon is not such a surface.

It is of course oa serious criticism of panspermia; how can a biospore transit the solar radiation field to reach another planet without being destroyed? To sustain the hypothesis, we might have to plead that the spore is embedded in some other protecting material, e.g., a particle of clay, or else that some hitherto unknown optical property of the spore in high vacuum might furnish some protection. The former plea makes it more difficult to accept Arrhenius' proposal of radiation pressure as the impetus to interplanetary transit. All this admitted, we do not feel that we have the intimate knowledge of conditions on the lunar surface and in interplanetary space to cast a decisive a priori judgment against the hypothesis.

In conclusion, we feel that general stress on minimizing contamination of any kind and excluding microorganisms as far as technically feasible is a plausible part of any cautious program of investigation. Rather than leave the moon for the uncontrolled deposit of uncontrolled contamination, it should be the testing ground for the same cautions as apply to the more sensitive planets.