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# Planetary Protection Issues and Future Mars Missions

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# PREFACE

This is the final report of a Workshop on "Planetary Protection Issues and the Human Exploration of Mars" conducted by NASA's Ames Research Center on March 7-9, 1990. It was jointly sponsored by the Office of Exploration and the Life Science Division both at NASA HQ. A preliminary report was presented at the 1990 meeting of the Commission on Space Research (COSPAR) in The Hague, and a paper on the subject is in press in *Advances in Space Research*.

Following the announcement of the Space Exploration Initiative (SEI) by the President, NASA embarked on a series of mission design studies to develop various options for the achievement of the goals of future robotic and human exploration of the Moon and Mars. During the course of these studies, it became clear that useful guidelines did not exist for mission planners and designers to evaluate the impact of existing Planetary Protection policy on mission architectures for either robotic precursor or manned missions to Mars. Therefore, this Workshop was conceived to develop an interim set of strawman guidelines for use by mission planners until official policy for the various missions under consideration could be established.

In order to achieve this goal, the Workshop considered both the possibility of forward contamination of Mars by terrestrial microbes carried on Mars-bound vehicles as well as the possibility of back contamination of Earth by species present in returned Mars samples. In addition to the scientific issues, the Workshop also attempted to assess the impact of non-scientific factors (including public, legal, international, societal, etc.) surrounding Planetary Protection on the implementation of exploration missions. This report contains strawman guidelines for Planetary Protection requirements for exploration missions, and also a series of recommendations for future research and development activities which may lead to a definitive settlement of the Planetary Protection issue.

The guidelines and considerations presented herein are not to be taken as official NASA policy but rather as interim strawman guidelines, to be used for mission design and other programmatic studies until official policy is established. Official policy for Planetary Protection for SEI missions will be set by NASA in consultation with the National Academy of Sciences and with the concurrence of the international scientific community under the auspices of COSPAR.

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# EXECUTIVE SUMMARY

This report describes the results from the Workshop on "Planetary Protection Issues and the Human Exploration of Mars."

Mars is a prime target in the continuing exobiological exploration of the solar system for clues concerning the origin, evolution, and distribution of life and life-related molecules. Although the Viking missions greatly expanded our knowledge of the planet, they were limited, in their search for organic chemicals and extant life, to examining surface samples from two fixed sites chosen more for spacecraft safety than scientific interest. In addition, extrapolation of Viking data from the two landing sites to the planet as a whole is not possible. Therefore, questions about the nature and extent of prebiotic chemical evolution, possible origin of life during a more clement era, and even the existence of extant life still remain open.

Although the existence of life on present-day Mars is improbable, it cannot be ruled out with certainty. Therefore, Planetary Protection (PP), which is concerned with prevention of harmful cross-contamination of planets during space exploration, must be addressed in the planning of future missions to Mars. There are two primary issues that must be considered: 1) forward contamination, which refers to upsetting a natural ecosystem that may exist on Mars by terrestrial microbes carried to the planet on spacecraft; and, 2) back contamination, which refers to upsetting the Earth's ecosystems by life-forms that may be present in a returned Mars sample. Insufficient and incomplete knowledge about Mars prevents an accurate assessment of exact risks in either case. As a result, and until additional data about Mars is obtained, a conservative approach is recommended in planning future missions. This is an important point because implementation of PP requirements can affect mission design, hardware, and costs.

PP requirements for Space Exploration Initiative (SEI) missions or Mission From Planet Earth (MFPE) were studied during a NASA-sponsored workshop. The purposes of the workshop were to identify key PP issues for SEI and to propose strawman guidelines for use in development of mission architectures. These guidelines would be preparatory to the development of official PP policy for SEI by NASA and the National Academy of Sciences, with the concurrence of the international scientific community through the Commission on Space Research (COSPAR).

The U.S. is signatory to a 1967 international treaty, monitored by COSPAR, which establishes the requirement to avoid harmful contamination of planets during space exploration. The PP policy revision of 1984 by NASA and COSPAR established the framework for developing PP guidelines for each of the individual missions that make up the SEI precursor mission set. This revised policy allows for tailoring of the implementing procedures to the type of mission design (lander, orbiter, sample return) being contemplated. Interim strawman guidelines for the SEI mission set were developed at the workshop on the basis of that framework.

In arriving at a set of strawman guidelines, it was assumed that PP issues will need to be dealt with in the precursor phase because deposition of microbes on Mars and exposure of the crew to Mars surface material will be inevitable once humans land. For the purposes of this workshop, the precursor mission set and sequence was assumed to be: Mars Observer, Global Network, Local Rover/Sample Return, High Resolution Orbiter, and Long-Range Rovers, as specified in the Report of the 90-day Study on Human Exploration of the Moon and Mars. However, it should be noted that this mission set has already undergone change and probably will continue to do so. For planning purposes, it was also assumed that Mars samples were hazardous until shown by testing to be safe, and that human landings would be unlikely until sample safety was demonstrated.

Based upon these assumptions, the following interim PP strawman guidelines are recommended for the various types of precursor missions:

1) To prevent forward contamination, all orbiters should be assembled under clean-room conditions, their trajectories should be biased to avoid unplanned impact, and they should meet certain orbital lifetime requirements. Additionally, all landers (including rovers, penetrators, surface stations, etc.) should be assembled under clean-room conditions, enclosed in a bio-shield, and treated to reduce microbial loads to acceptable limits. For landers, there might be other requirements imposed by biology or chemistry investigations that might be part of the payload. These are, in fact, the same guidelines that were used for the Mars Observer and Viking missions.

2) To prevent back contamination, all sample return missions should have landers that are encapsulated in a bio-shield and treated to reduce the microbial load to acceptable limits. The sample should be placed in a hermetically sealed container, preserved under Mars ambient conditions, and the contact chain with Mars' surface should be broken in order to prevent the transfer of un-contained surface material to the Earth on the exterior of the return vehicle. In addition, the sample should be returned to a high-containment facility on the Earth and subjected to a comprehensive quarantine protocol to investigate whether or not harmful constituents are

present. These guidelines have not been reviewed by the National Academy of Sciences, but have been discussed in the international forum of the 1988 COSPAR meeting.

In addition to adopting these strawman guidelines, several other issues relevant to PP and the SEI were discussed at the workshop and require further analysis and evaluation. Some examples of the discussion are summarized in the following paragraphs:

With regard to assessing the probability of forward contamination, the possible survival and distribution of terrestrial microbes on Mars need to be better understood. More information is needed on Mars' environmental properties, especially at scientifically interesting sites. This suggests that in a realistic precursor mission set, a mission like the High Resolution Orbiter should occur early in the sequence. Detection of extant life during the precursor phase will undoubtedly cause a delay in human missions while the life-forms are characterized and their potential hazard and control are evaluated. It is recommended that biological and chemical contamination of Mars by human missions be minimized even if the results of precursor missions are negative with regard to extant life, since exobiological exploration for evidence of chemical evolution and past or present life is likely to be a continuing objective. In addition, the monitoring and characterization of any contamination of surface materials that may occur would also help preserve options for future scientific investigations.

Dealing with back contamination hinges to a large extent on comprehensive analysis of returned Mars samples. Emphasis should again be on samples from scientifically interesting sites, that is, sites that may possibly have liquid water (even intermittently) or anomalous heat, chemistry, or atmospheric conditions. In addition, samples from below the surface or from chemically well-characterized sites would make the returned samples more valuable for scientific investigations. Although many feel that a returned Mars sample containing microbes of unknown properties can be adequately contained on the Earth, others argue that this approach would subject such a mission to the highest degree of public concern. Therefore, further *in situ* biological tests on Mars should be done prior to any return of a samples to the Earth. This would require having on board the Local Rover/Sample Return or other lander missions the capability to perform sophisticated life detection experiments on Mars, before return of the sample to the Earth is authorized. It is further recommended that precursor sample return missions include samples from sites representative of the future human landing sites, and that the mission design should guard against uncontrolled re-entry of the return vehicle into the Earth's atmosphere.

Although forward contamination will likely be less of an issue with the public, it is anticipated that return of a sample from Mars could engender significant concern on the part of the public over the possibility that the sample contains components that could be harmful to the Earth's biosphere. It is imperative that NASA strive for public education and informed public consent well in advance of such a mission. In part, these concerns can be mitigated by establishing a continuing and visible advisory structure and by asking the National Research Council (NRC) to conduct a study on the possible hazards posed by extraterrestrial biological species. Experience with the Apollo program indicates that statutory requirements of other agencies need to be understood at an early date and legal, treaty, and international implications need to be defined and enacted or amended if needed. An active PP program needs to be re-established within NASA and funded adequately in order to deal with these issues. In addition, the Agency should examine its current PP role for potential conflicts of interest and take steps to rectify problem areas, as needed.

# INTRODUCTION

## WORKSHOP OBJECTIVES

The Workshop on "Planetary Protection Issues and Human Exploration of Mars" was held March 7 - 9, 1990 at Hyatt Rickeys Hotel, Palo Alto, California. The Workshop was organized by Donald L. DeVincenzi, Deputy Chief, Space Science Division, NASA Ames Research Center and Co-chaired by Harold P. Klein, Santa Clara University and John R. Bagby, Missouri State Department of Health. The Workshop attendees included 9 invited speakers and 32 participants. The participants were chosen to cover the broad range of Planetary Protection related topics to be discussed at the Workshop. Participating scientists representing the fields of astrophysics, atmospheric chemistry, biology, chemistry, ecology, environmental science, geology, geochemistry, instrumentation design, and microbiology, were joined by journalists and representatives from the legal community. Participants were selected from NASA and other U.S. Government agencies, universities, private industry, and the international scientific community.

The objective of the Workshop was to recommend interim guidelines for Planetary Protection (PP) requirements for the Space Exploration Initiative (SEI) missions to Mars in order to provide input to mission design and analysis studies, and to identify long-lead time elements for early study. Emphasis was placed on the need to gain information from precursor missions to settle questions related to Planetary Protection issues prior to any human exposure to martian materials.

The structure of the 3-day Workshop consisted of one full day of background presentations, in which Planetary Protection experience from past missions was reviewed, current knowledge of the environment of Mars was described, and societal and legal Planetary Protection issues were outlined. The formal presentations were accompanied by two short panel discussions which were followed by the development of working assumptions and strawman guidelines. At the end of the first day three topical sub-groups (forward contamination, back contamination, and societal/legal implications) were formed from the full roster of attendees; the sub-groups were charged to examine the Planetary Protection assumptions, guidelines, and issues related to their specific topic area. The entire second day consisted of these individual sub-group discussions, and by the end of the day each sub-group had generated a list of recommendations, key points of consideration, and concerns for its topic area. The third day began with a review of the status of NASA's Space Exploration Initiative (SEI). This was followed by detailed oral reports from each sub-group on its discussions, findings, and recommendations.

A preliminary presentation of the results of this workshop was made at the 1990 meeting of COSPAR in the Hague, the Netherlands. A paper on the subject is in press /1/.

As this report was being prepared, it became clear that a list of key references to the Planetary Protection literature would be a useful addendum and would greatly assist those involved in dealing with the issue of Planetary Protection in this new era of exploration. Therefore, in addition to noting specific references in each chapter, a more comprehensive bibliography has been assembled and is included as an integral part of this report (see Appendix).

## ASSUMPTIONS AND GUIDELINES

The United States is signatory to an international treaty /2/, monitored by COSPAR, which establishes the requirement to avoid biological cross-contamination between the Earth and other planets during space exploration missions. The Planetary Protection (PP) policy revision conducted by NASA, and accepted as official COSPAR policy /3/, lays out a framework for developing specific PP guidelines and implementing procedures for future missions, including the missions to Mars that make up the Space Exploration Initiative (SEI) set. This revised policy allows for tailoring the implementing procedures to the type of mission design (orbiter, lander, or sample return) being contemplated. The strawman PP guidelines for the SEI Mars mission set were developed on the basis of this framework.

In arriving at a set of interim guidelines, a conservative approach to Planetary Protection was adopted. For example, it was assumed that PP issues will need to be dealt with in the unmanned precursor phase because deposition of microbes on Mars (forward contamination) and exposure of the crew to Mars surface material (back contamination) will be inevitable once humans land. A conservative approach also meant that Mars samples were to be treated as if they were hazardous and that at least the initial sample return missions would have to be conducted under conditions of complete sample containment and extensive quarantine testing. Finally, it was further assumed that human landings would be delayed until it was shown that the martian material had no harmful effect on terrestrial life forms.

To assess the utility of various unmanned precursor missions for acquiring the knowledge necessary for Planetary Protection purposes, the Workshop assumed that the precursor mission set and sequence was the one specified in the 90-Day Study Report /4/: 1) Mars Observer, an orbiter to establish global martian data bases; 2) Global Network (now called MESUR, Mars Environmental Survey), multiple landers to provide *in situ* surface analyses at several locations; 3) Sample Return with Local Rover, to return Mars samples from outside the immediate landing area to the Earth for detailed analysis; 4) Mars Site

Reconnaissance Orbiter (also known as High Resolution Orbiter), for detailed characterization of potential human landing sites; and, 5) Long-Range Rovers, to certify the sites for piloted missions and establishment of an outpost. Although this mission set and sequence was assumed to be accurate for the purposes of the Workshop, it has subsequently undergone significant changes in both content and sequence and will probably continue to do so.

Given these assumptions, the following Planetary Protection strawman guidelines were proposed for the various types of unmanned precursor missions:

1) To prevent forward contamination of Mars with terrestrial microbes, all orbiters in the precursor mission set should be assembled in a clean-room to minimize initial microbial load, their trajectories should be biased to avoid unplanned impact and release of microbes from an untreated spacecraft, and they should meet certain orbital lifetime requirements to assure that impact will not occur until biological exploration of the planet is reasonably complete. These guidelines are, in fact, the same as the implementing procedures actually in place now for the Mars Observer mission /5/, as recommended by the National Academy of Sciences and based on the current NASA and COSPAR policy.

2) Additionally, to prevent forward contamination, all Mars lander vehicles (including rovers, penetrators, surface stations, etc.) should be assembled in a clean-room, they should be subjected to appropriate procedures to achieve prescribed microbial load reduction requirements, and re-contamination should be prevented by enclosing the lander vehicles in a bio-shield. These guidelines are, in fact, the same as those used to derive the Viking mission requirements /6/. It should be noted that the final Viking heat treatment requirement reflected both the need to prevent contamination of the Mars surface with terrestrial microbes as well as the need to preserve the integrity of the biology and chemistry investigations which were part of the science payload.

3) To prevent back contamination of the Earth with potentially hazardous species in the martian samples, all sample return missions should enclose the sample in a hermetically sealed container. Furthermore, the contact chain between the return vehicle and the Mars surface must be broken by some appropriate means in order to prevent the transfer of un-contained surface material from Mars to Earth on the spacecraft exterior. In addition, the sample should be returned to a specialized containment facility on Earth, as opposed to an Earth-orbiting or lunar laboratory, and subjected to a comprehensive quarantine protocol, as recommended in the current PP policy, to investigate whether or not harmful constituents are present. Finally, to preserve the integrity of

returned samples for scientific analyses for the presence of indigenous life forms, the landers and sampling equipment on the outbound spacecraft should achieve prescribed microbial load reductions and be encapsulated in a bio-shield to prevent re-contamination, and the sample should be preserved under conditions that closely match martian ambient conditions during the return to Earth. These guidelines for PP requirements for sample return missions were developed only recently and have not yet been reviewed and approved for implementation by the National Academy of Sciences, but they have been discussed in the international community /7/.

In the longer term, and according to NASA policy and procedures detailed in the revised Planetary Protection policy, the National Academy of Sciences will be asked to recommend specific requirements for PP implementation on each mission in the SEI precursor set. In the meantime, the strawman guidelines presented here can be used by mission designers and planners who need to anticipate the impact of PP procedures on SEI mission scenarios and architectures. In addition, this analysis can be used to define a set of studies which could be initiated in the near term to acquire data that will be needed before official procedures can be fully specified (e.g., evaluation of techniques other than heat which could be used to achieve microbial load reductions, or development of the technology needed to break the contact chain between Mars surface material and the Earth-return vehicle).

## REFERENCES


/1/ DeVincenzi, D.L., "Planetary Protection Issues and the Future Exploration of Mars," *Adv. Space Res.*, in press, 1991.

/2/ "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," Article IX, U.N. Doc. A/RES/2222(XXI) January 27, 1967; TIAS No. 6347, IN: *U.S. Treaties and Other International Agreements.* ***18***, pp. 2410-2498, 1967.

/3/ DeVincenzi, D.L. and P.D. Stabekis, "Revised Planetary Protection Policy for Solar System Exploration," *Adv. Space Res.* ***4(12)***, pp. 291-295, 1984.

/4/ Cohen, A., *Report of the 90-day Study on Human Exploration of the Moon and Mars*, NASA, Washington, D.C., 1990.

/5/ *Mars Observer Planetary Protection Plan*, JPL Report D-2749, Jet Propulsion Laboratory, Pasadena, CA, October 1985.

/6/ Daspit, L., J. Stern, and J. Martin, *Lessons Learned from the Viking Planetary Quarantine and Contamination Control Experience*, NASA Contractor Report NASW-4355, NASA, Washington, D.C., September 27, 1988.

/7/ DeVincenzi, D.L. and H.P. Klein, "Planetary Protection Issues for Sample Return Missions," *Adv. Space Res.* ***9(6)***, pp. 203-206, 1989.

# BACKGROUND

## ORIGINS OF PLANETARY PROTECTION POLICY

Early discussions regarding the potential need for Planetary Protection as a result of space missions began soon after the Soviet launch of Sputnik in 1957 /1, 2/. By 1964, the international community, through COSPAR, became involved in these discussions, resulting in the adoption of a set of recommendations for the protection of the planets and for the reduction of microbial loads on spacecraft /3/. Quantitative objectives were agreed upon, based upon such factors as the number of missions to a planet, the estimated number of organisms on the spacecraft, and the probabilities of releasing organisms on a planet and of their growth in that environment. COSPAR recommended reducing microbial loads on spacecraft, favoring the use of heat treatment,

> " . . . such that the probability of a single viable organism aboard any vehicle intended for planetary landing or penetration would be less than $10^{-4}$ and a probability limit for accidental planetary impact by un-sterilized orbiting spacecraft of $3 \times 10^{-5}$ or less . . . during the interval terminating at the end of the initial period of planetary exploration by landing vehicles (approximately one decade)."

Estimates on the number of space missions to Mars during the anticipated period of planetary exploration varied enormously. Sagan and Coleman /4/ estimated 60 landers and 30 flyby and orbiter missions, and a total of 1200 biological experiments; Hall /5/ proposed a realistic maximum number of about 100 landing capsules and non-landing vehicles over a 20 year period.

These early discussions of Planetary Protection culminated, in 1966, in the inclusion of Article IX in the Treaty on Space /6/. Unanimously adopted by the United Nations General Assembly, this article declared that:

> "States party to the treaty shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in . . . space . . . with due regard to the corresponding interests of all parties. Parties shall pursue studies . . . so as to avoid their harmful contamination and also

adverse changes in the environment of the Earth resulting from the . . . introduction of extraterrestrial matter . . . "

A year later, COSPAR convened the first international symposium devoted to the subject of heat treatment of spacecraft, which resulted in the publication of a set of quantitative parameters for implementing Planetary Protection /7/.

Also in 1967, NASA, adopting the COSPAR policy for quantitative objectives for Planetary Protection, established a Planetary Protection Office and issued a directive /8/ for space missions based upon the use of probabilistic models. This directive guided mission planners until 1984, when NASA and COSPAR revised the existing policy /9/. Subsequently, NASA issued new guidelines in NMI 8020.7A /10/.

The revised policy of 1984 sustains the commitment by space-faring nations to preserve natural planetary environments but eliminates the blanket quantitative guidelines from the policy statement itself. It de-emphasizes, but does not eliminate, the use of mathematical models as the implementing approach and reserves application of quantitative criteria for only selected cases (e.g., Mars lander missions). Under the revised policy, implementation of Planetary Protection provisions is accomplished by exception, with excepted cases being defined by both the target planet (e.g., Mars) and the mission type (e.g., lander).

## PLANETARY PROTECTION AND THE APOLLO PROGRAM

Barely three years before the launch of Apollo 11, NASA established an Interagency Committee on Back-Contamination to advise on procedures to protect the Earth's biosphere from potential lunar contaminants. The recommendations of this group resulted in the development of quarantine protocols and the establishment of special facilities at NASA's Johnson Space Center (formerly the Manned Space Flight Center). A biomedical facility was to be used for the quarantine of astronauts after their return from the Moon, and a Lunar Receiving Laboratory was to be used in which lunar samples were to be assayed for possible deleterious factors.

The subsequent implementation of the committee's recommendations was not free of problems. Some of these were dictated by real-time operational considerations, while some were clearly based on philosophical grounds.

Ultimately, during the program, eighteen astronauts, 380 kg of lunar samples, and six command modules were returned to the Earth. As recommended, Apollo crews followed decontamination procedures within the Lunar Excursion Module (LEM) to prevent lunar material from contaminating the Command Module (CM) before its return to the Earth, and special microbial filters cleaned the spacecraft's atmosphere in the CM. However, when Apollo 11 returned, a vent was opened to the Earth's atmosphere releasing any contaminants which may have been present. Furthermore, after the CM splashed down, the spacecraft hatch was opened to pass protective suits to the astronauts, thus causing an additional breach in the quarantine process. Planetary Protection was breached again, later, when a helicopter brought the crew from the CM to the shipboard mobile quarantine facility.

To these examples of operationally-derived problems must be added a number of major philosophical difficulties which, from the outset, faced the quarantine program. These ranged from overt resistance by flight personnel to the proposed procedures to fundamental problems concerning the ability and authority of NASA to regulate those non-NASA personnel who were to be involved in various aspects of the quarantine process. Responsibility for the Apollo Planetary Protection program was placed at the Manned Space Flight Center. Not surprisingly, top priority at the Center was crew safety and operating the missions on schedule, sometimes resulting in diminished attention to the implementation of quarantine procedures. Construction of the Lunar Receiving Laboratory was started too late for adequate training of personnel who were to staff this facility. This deficiency was most acute in the case of the scientists who were to use the facility, many of whom arrived at the laboratory too late to become familiar with the operational procedures in the facility. Once under way, the quarantine process was also marred by the free passage of laboratory personnel in and out of the facility without adequate decontamination. These and other instances in the Apollo quarantine experience illustrate the need for long lead-times and firm commitment for a program of Planetary Protection. (The Apollo experience has been reviewed in detail by Bagby /11/).

## PLANETARY PROTECTION AND U.S. MISSIONS TO MARS

During the 1960s considerable effort was directed to defining the requirements for implementing Planetary Protection policy for Mars missions, to establishing methods to meet these requirements, and to developing the requisite hardware for the missions. NASA accepted the COSPAR guidelines /12/, which specified that " . . . the probability of contamination by terrestrial microorganisms of a planet of biological interest shall not exceed one chance in one thousand . . . ," and conducted the early Mariner missions to Mars with these standards in mind. For these flyby and orbiter missions, the guidelines were implemented by assembly of the spacecraft in clean rooms, and by the selection of appropriate trajectories and aim-points.

With the approval of the Viking mission, "sterilization" of the landers (i.e., reduction in the biological load on the spacecraft to levels that would meet the COSPAR probabilistic guidelines) became inevitable. Procedures were developed which are documented in NASA policy directives /13, 14, 15/. Since the Viking orbiters had to have a lifetime of 50 years in orbit extending to the year 2018 (to cover the expected period of exploration of Mars before a human landing), the guidelines required establishing a minimum periapsis altitude for each spacecraft. Each Viking lander (containing approximately 60,000 parts) was ultimately encapsulated in a sealed, pressurized, bio-shield and "sterilized" in a specially built oven at Kennedy Space Center, using dry heat at low relative humidity in an inert gas environment. Heat treatment was carried out at 125°C for qualification testing, and at 113°C for acceptance testing. The final heating cycle in each of the two Viking landers was approximately 30 hours at 117°C. Microbial sampling of spacecraft components, together with analytical models and computer techniques, were used to estimate the total microbial burden, to characterize the thermal properties at various locations in the landers, and to model thermally the progress of the heating process. Heating was continued until the calculated microbial burden throughout each lander fell to an acceptable level.

Additional precautions were taken because of the presence of the Viking Biology investigations. For these experiments, an additional requirement was imposed by the Biology Team - that the probability of contamination of their instruments be $10^{-6}$ or less. This requirement was met by a separate heat treatment of the biology instruments (120°C for 54 hours) prior to their installation in the Viking landers.

Since the Mars Observer mission (MO) presently under development is an orbiter, the mission was categorized as a Category III mission under the current NASA policy on Planetary Protection. This necessitated: 1) assembly of the spacecraft and payloads in Class 100,000 clean-rooms; 2) biasing the aim-point of orbit injection so as to minimize the probability of impacting Mars (probabilities of $10^{-4}$ for the spacecraft and $10^{-5}$ for the launch vehicle); 3) selecting an orbit such that the probability of remaining in orbit until the year 2009 is 0.9999 or better; and raising the orbit after the nominal mission such that a stable orbit would be maintained until the year 2039 with a probability of 0.95 or better.

## PLANETARY PROTECTION AND SOVIET MISSIONS TO MARS

At present, there is no readily available information about the details of Soviet implementation of the COSPAR guidelines for Planetary Protection. Some are of the opinion that Soviet missions have already contaminated Mars by flying untreated spacecraft to the planet. In the absence of more specific information, however, there is reason to believe that precautions have been taken in this regard.

From news reports and the available literature, the Soviets appear to have attempted 17 missions to Mars beginning soon after the launching of the first Sputnik (see Table 1 taken from a book by E. Burgess /16/). Five of these missions (designated with asterisks, *) were intended to land on the planet. Of these, three probably made it to the surface safely (designated with daggers, †) but were short-lived and communications with them ended prematurely.

| NAME | LAUNCH DATE | ARRIVAL DATE |
|---|---|---|
| (none) | 10 October 1960 | Failed |
| (none) | 14 October 1960 | Failed |
| (none) | 24 October 1962 | Failed |
| Mars 1 | 1 November 1962 | Failed |
| (none) | 4 November 1962 | Failed |
| Zond 2 | 30 November 1964 | Failed |
| Zond 3 | 18 July 1965 | Failed |
| (none) | 27 March 1969 | Failed |
| Kosmos 419 | 10 May 1971 | Failed |
| Mars 2 *† | 19 May 1971 | 27 November 1971 |
| Mars 3 *† | 28 May 1971 | 2 December 1971 |
| Mars 4 * | 21 July 1973 | 8 February 1974 |
| Mars 5 * | 25 July 1973 | 12 February 1974 |
| Mars 6 *† | 5 August 1973 | 12 March 1974 |
| Mars 7 | 9 August 1973 | 9 March 1974 |
| Phobos 1 | 7 July 1988 | Failed |
| Phobos 2 | 12 July 1988 | 29 January 1989 |

Table 1: Soviet Missions to Mars

It also appears that the Soviets attempted to decontaminate their Mars spacecraft. Soviet newspaper reports pertaining to these missions, without being specific, consistently maintained that these spacecraft conformed to the COSPAR guidelines. It is also clear that the Soviets initiated programs to develop techniques for spacecraft decontamination early in the 1960s, publishing many papers describing the use of radiation, chemicals, and heat, either singly or in combination, to treat their spacecraft. In this regard, this program of Soviet research in Planetary Protection closely paralleled research in the U.S.

While it is known that the Soviets actively engaged in laboratory studies on Planetary Protection, and published papers on these studies, no literature is available on the application of these techniques to actual missions. However, in a report to COSPAR in 1973, they gave general information on their "Mars" series of spacecraft /17/. For these, each sub-component was first treated by heat, gas, chemical, or radiation. The final spacecraft was then assembled in an "ultra-clean" room. For each of these missions, three identical spacecraft were built, of which one was disassembled and the pulverized sub-components assayed to verify that decontamination had been achieved before launching the other two. While these methods would appear to assure compliance with the intent of the COSPAR guidelines, it is known that although the spacecraft may be biologically clean when sent to the launch site, launching takes place under military command over which the Planetary Protection team had no jurisdiction. Finally, in recent years, the Soviets have consistently stated that they have met, and intend to continue to meet, the COSPAR guidelines on Planetary Protection.

## THE ENVIRONMENTAL HISTORY OF MARS: IMPLICATIONS FOR PLANETARY PROTECTION

Much of our present understanding of the geological history of Mars has been derived from analysis of the results of the Viking mission. The available data indicate that, over geological time, the surface of Mars has been molded by both endogenic and exogenic processes, including volcanism, tectonics, erosion, transportation, deposition, and impact cratering (see Table 2).

During the earliest (Noachian) geological period iron-rich basaltic lavas flowed in thin sheets over the inter-crater plains. Also small valley networks were formed and these suggest that there was liquid water on the surface which may have soaked back into the regolith where it may now be stored.

In the Hesperian period there was central vent volcanism and still some partial covering of the surface by flood lavas. A major event was the opening of the Valles Marineris, a tectonic feature comprising a western section of intersecting fractures, a middle section of major canyons trending east to west, and an eastern section of a large area of chaotic terrain which appears to have been the source of water that flowed in several episodes into Chryse Planitia. This period also saw the growth of the Tharsis bulge and the construction of the major volcanoes, some of whose flows extended for thousands of kilometers.

In the most recent (Amazonian) period, the surface was further changed. Lava flows filled the northern plains, and peculiar fracture patterns were generated. Some volcanic flows have no impact craters. There are small fluvial and volcanic channels.

| GEOLOGICAL PERIOD | ACTIVITY | ESTIMATED TIME |
|---|---|---|
| Noachian | Early explosive volcanism | 4.6 by |
| | Extensive erosion/deposition (mantles) | |
| | Volcanism; ridged plains | |
| | Crustal dichotomy arises | |
| | Basin formation (Hellas, Argyre) | |
| | Heavy impact cratering | |
| | Liquid water channels form | 3.5 by |
| Hesperian | Large channels | 3.5 by |
| | Deposition (V. Marineris, N. plains) | |
| | Volcanism (Syrtis Major, Tharsis) | |
| | Tectonics (Tharsis) | |
| | Early "central" volcanism (paterae) | |
| | Tectonics (Isidis, Memnonia, V. Marineris) | |
| | Volcanism; extensive ridge plains | 1.8 by |
| Amazonian | Aeolian activity | 1.8 by |
| | Polar deposits | |
| | Olympus Mons; younger lavas | |
| | Late state (fluvial?) channels | |
| | Northern plains units | Present |

Table 2: Geological Time-Scale for Mars.

The present distribution of volatiles on Mars includes the polar caps, the atmosphere and the regolith. At the poles volatiles are concentrated in three regions. Frozen carbon dioxide covers a large area during winter at each pole. This seasonal concentration of carbon dioxide at the poles results in an annual change of 30% in the atmospheric pressure on Mars. Secondly, in the northern hemisphere, water ice forms a smaller but more massive polar cap. The low albedo of the ice cap (less than that of terrestrial ice) indicates that the martian ice contains much dust. A third polar unit is even more massive and consists of layered deposits of ice and dust extending some ten degrees from the pole.

The south polar cap currently differs from its northern counterpart. The carbon dioxide ice is offset from the pole and when the frost cap disappears in the summer, the residual cap is of carbon dioxide, not water ice like the northern residual cap. The southern cap is believed to be a recent configuration. Large oscillations in obliquity experienced by Mars probably account for changes in configuration of the caps.
A major phenomenon on Mars may be adsorption, by which gases can be accumulated at a solid surface. As the surface temperature decreases the gas ultimately condenses to liquid. Adsorbed carbon dioxide in martian soil could be at a pressure of 0.3 bar, with much more carbon dioxide in the regolith than in the atmosphere of the planet. Changes in obliquity would change the amount of carbon dioxide in the soil. Also at periods of high obliquity solar heat is more evenly distributed, volatiles enter the atmosphere from the polar caps and the atmospheric pressure rises to the point at which more intense dust storms can be generated.

There are probably extensive deposits of water ice beneath the surface of Mars especially at higher latitudes. However in equatorial regions there may even be highly saline pockets of water. There also may be groundwater on Mars starting at a depth of one kilometer near the equator, to below two kilometers at higher latitudes, and below three kilometers at the poles. While there is abundant water and heat on Mars, at the present time these do not appear to coincide at places where they could maintain liquid water and a biota.

To summarize, although today Mars is a cold, dry desert swept by dust storms, it is apparent that Mars had a wet, warm past during the Noachian period which may have been conducive to biological development from prebiotic molecules. Because life on the Earth arose during Mars' Noachian period (i.e., more than 3.5 by ago), Mars offers a unique testing ground to determine whether chemical evolution leading to a carbon-based replicating system also occurred there when conditions may have been suitable for the origin of life. Corollary to this central point are two possible consequences of such an initial development of life: 1) if a living system did arise on Mars, was it able to adapt to deteriorating conditions as the planet lost most of its atmosphere, cooled down and dried out, or, 2) are these ancient organisms now extinct? A few scientists believe that living organisms may still be present on Mars in as yet unidentified niches, while the Viking results have led most scientists to conclude that there was no extant life on Mars at the two Viking Lander sites and that the probability is high that none exists anywhere else on the planet.

## REFERENCES

/1/ Committee on Extraterrestrial Exploration (CETEX) Report, "Development of International Efforts to Avoid Contamination by Extraterrestrial Exploration," *Science* ***128***, pp. 6887-6889, 1958.

/2/ Committee on Extraterrestrial Exploration (CETEX) Report, "Contamination by Extraterrestrial Exploration," *Nature* ***183***, pp. 925-928, 1959.

/3/ Commission on Space Research (COSPAR), *Statement on the Potentially Harmful Effects of Space Experiments Concerning the Contamination of Planets*, COSPAR Information Bulletin No. 20, pp. 25 - 26, Geneva, Switzerland, 1964.

/4/ Sagan, C. and S. Coleman, "Spacecraft Sterilization Standards and Contamination of Mars," *Astronaut. Aeron.* ***3***, pp. 22, 1965.

/5/ Hall, L.B., "The Importance of Sterilization Techniques in Space Exploration," IN: *Sterilization Techniques for Instruments and Materials as Applied to Space Research*, P.H.A. Sneath, ed., COSPAR Technical Manual No. 4, pp. 3-18, 1968.

/6/ "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," Article IX, U.N. Doc. A/RES/2222(XXI) January 27, 1967; TIAS No. 6347, IN: *U.S. Treaties and Other International Agreements.* ***18***, pp. 2410-2498, 1967.

/7/ Lederberg, J. and C. Sagan, "Relationship of Planetary Quarantine to Biological Search Strategy," *Life Sci. and Space Res.* ***VI***, pp. 136-145, 1968.

/8/ *Outbound Spacecraft: Basic Policy Relating to Lunar and Planetary Contamination Control*, NASA NPD-8020.7, NASA Washington, D.C., September 6, 1967.

/9/ DeVincenzi, D.L. and P.D. Stabekis, "Revised Planetary Protection Policy for Solar System Exploration," *Adv. Space Res.* ***4(12)***, pp. 291-295, 1984.

/10/ *Biological Contamination Control for Outbound and Inbound Planetary Spacecraft*, NASA NMI-8020.7A, NASA, Washington, D.C., 1988.

/11/ Bagby, Jr., J.R., *Back Contamination: Lessons Learned During the Apollo Lunar Quarantine Program*, JPL CR-560226, Jet Propulsion Laboratory, Pasadena, CA, 1975.

/12/ Commission on Space Research (COSPAR), *Statement on the Potentially Harmful Effects of Space Experiments Concerning the Contamination of Planets*, COSPAR Information Bulletin No. 20, pp. 25 - 26, Geneva, Switzerland, 1964.

/13/ *Outbound Spacecraft: Basic Policy Relating to Lunar and Planetary Contamination Control*, NASA NPD-8020.7, NASA Washington, D.C., September 6, 1967.

/14/ *Outbound Planetary Biological and Organic Contamination Control: Policy and Responsibility*, NASA NPD-8020.10, NASA, Washington D.C., August 1972.

/15/ *Quarantine Provisions for Unmanned Extraterrestrial Missions*, NASA NHB-8020.12A, NASA, Washington, D.C., February 1976.

/16/ Burgess, E., *Return to the Red Planet*, Columbia University Press, New York, NY, 1990.

/17/ Vashkov, V.I., N.V. Ramkova, G.V. Scheglova, L.Z. Skala, and A.G. Nekhorosheva, "Verification of the Efficiency of Spacecraft Sterilization," *Life Sci. and Space Res.* ***XII***, pp. 119-202, 1974.

# SCIENTIFIC ISSUES

## FORWARD CONTAMINATION

Implementation of techniques to prevent forward contamination has as its primary goal to protect a martian biota from any terrestrial microorganisms that might be carried on spacecraft. While it does not seem likely that such a biota exists on Mars, current data do not rule out this possibility. If an indigenous martian biota does exist, the release of terrestrial organisms may have an impact on it which cannot adequately be assessed.

### Terrestrial Organisms and the Martian Environment

The survival and growth of terrestrial organisms on Mars is dependent on the physics (e.g., solar radiation, temperature) and chemistry (e.g., availability of liquid water and nutrients, presence of oxidants) of the martian environment. The harsh conditions on the surface would seem to preclude the survival and growth of either introduced or indigenous biota in any areas of the planet except in as-yet unidentified, protected microenvironments ("oases"). Candidate microenvironments that have been suggested in the past include the interiors of rocks, regions surrounding the north polar water ice cap, evaporites, the subsurface zone, and volcanic vents. Analogous terrestrial microbial communities are known, and it is conceivable that some terrestrial contaminants carried to Mars could survive similar environments there. In addition, many species of microorganisms form highly resistant spores or resting stages that may afford them some temporary protection from the rigors of the martian environment.

The low temperatures and dry surface conditions on Mars suggest that growth and proliferation of terrestrial organisms are unlikely, but even with little or no growth, the mere ability of organisms to survive on Mars raises concerns, since the release of viable organisms may confuse the results of future searches for life or for organic chemistry on Mars.

## General Approaches to Forward Contamination Control

For the reasons discussed above, and based on current policy, future mission planning that entails landing on Mars should include precautions to prevent forward contamination.

A conservative approach is proposed for mission planning purposes for the prevention of forward contamination throughout the precursor phase. It is envisioned that whether or not life detection experiments are part of lander or rover missions, those missions will land and rove in areas that may be of interest to subsequent biological investigations, thus warranting this conservative approach. Even if life detection experiments are included in a specific mission during the precursor phase, and that mission fails to detect life, it would be prudent not to extrapolate from that mission to follow-on missions which are likely to investigate other locales on Mars. Later, as future findings are analyzed, reassessment of the data obtained from Mars may ultimately result in the relaxation of this approach.

All hardware intended to land on the surface of Mars should be treated to reduce bio-load. Limiting the treatment only to those lander elements directly involved in the sample collection is inadequate to protect either any potential biology investigations or the planet. In general, the same approach to implementation as was used on the Viking landers and orbiters should be used during the robotic precursor phase of Mars exploration. This approach, based on current policy, includes treatment of all landed hardware to specifications similar to those used for Viking, as well as: 1) cleaning of non-landed mission hardware (e.g., orbiter, shroud, etc.) to prescribed levels of biological loads; 2) maintenance of these levels of cleanliness through the effective use of bio-shields (for treated hardware), clean-room assembly and processing, clean transporters, filtered air (class 100,000 or better) on transporters and at the launch pad; and 3) other procedures as determined by analyses. Additional organic chemical contamination requirements should be defined and implemented.

Life on Mars, if it currently exists, will probably be found in an "oasis." Therefore, it will be necessary to assess a number of representative physical/chemical/geological areas during the precursor phase of Mars exploration, to determine whether any oases do, in fact, exist on Mars. To optimize the search for sites with possible biologically relevant properties, a revision to the mission set described in the 90-day report is proposed which would move the High Resolution Orbiter earlier in the sequence. The revised sequence might be:

- Mars Observer
- Global Network
- High resolution orbiter

- Local rover with sample return
- Long range rover with sample return
- Three or more local rovers with sample return

Furthermore, each of these missions should be spaced at intervals that will provide sufficient time for planning and implementation of the subsequent missions, allowing for the development of new experiments and instruments.

If, on any mission during the precursor phase, evidence for martian life is obtained (as a result of *in situ* analyses or in returned samples), the planned series of subsequent flights should be reappraised. At such a point, follow-on missions should emphasize: 1) characterizing the biosphere and determining its chemical and physical properties; and 2) biologically and chemically characterizing the nature and diversity of extant life forms. It is not feasible to predict in advance the types, duration, or intensity of investigations that will be necessary to accomplish this. Most particularly there should be no human landings until these studies have been completed.

Since questions about life on Mars may well persist beyond the robotic precursor phase, even if no evidence is obtained for a martian biota, a desire to continue exobiological exploration even after humans land on Mars may remain. Under these circumstances, some appropriate contamination control procedures may still be needed. Minimum requirements might include mineralization or removal from Mars of organic by-products of human exploration or monitoring and characterization of any contaminating materials.

## Future Directions for Forward Contamination Research

To help address many of the uncertainties inherent in evaluating the issue of forward contamination, a wide range of information must be obtained. Of paramount importance are further studies of the physical and chemical environment of Mars; for example, further studies on its surface chemistry and status and distribution of water. The ability of terrestrial microorganisms to survive and to reproduce under simulated martian conditions should be studied in the light of new data on the diversity of terrestrial microbes and new data on the environment of Mars.

To encompass these proposed studies, construction of a ground-based facility that would simulate the martian chemical and physical environment as closely as possible may be desirable. Such a facility would serve a number of scientific purposes as the Mars mission set unfolds. It could be used to study the transport, survival, and/or growth of microorganisms under simulated martian conditions. The facility could also be used to duplicate survival/growth experiments using martian soils from sample return missions. The scientific specifications should include atmospheric pressure and composition control, appropriate solar spectrum control with temporal variation, and temperature control. As more is learned from the precursor missions, the facility could be suitably modified and upgraded to accommodate subsequent relevant experiments.

## BACK CONTAMINATION

Even if the preponderance of scientific evidence argues against the presence of indigenous life on Mars, this possibility must be considered as part of any serious Planetary Protection analysis for missions to Mars. This is particularly true in considering the return of a sample to Earth from Mars.

Before a robotic sample return mission can be adequately planned, further information about the environment of Mars is needed. This information would primarily be used to select the site(s) from which samples would be returned; i.e., to determine if there are any special locations on Mars likely to harbor life. This information can be obtained not only by spacecraft traveling to Mars but also by observations from Earth-based or orbital facilities.

The absence of liquid water on the surface of Mars is probably the most serious argument against the presence of life anywhere at the surface of the planet. Liquid water is the quintessential requirement for life, and merely finding liquid water on the surface of Mars will certainly lead to a reassessment of the probability of finding indigenous life there. Therefore the most important requirement for further information about Mars is a search for possible "oases" containing even transient liquid water anywhere on the planet. Locations that are of particular interest in this regard are: 1) areas with transient melting of ice or snow, 2) near-surface brine solutions, and 3) sub-surface reservoirs of melt-water within the regolith or at the base of the polar caps, possibly geothermally driven.

In addition to liquid water, there may be other indicators that a habitat favorable to life can exist on Mars. This could include sites of unusually high geothermal heat flow, possibly indicating a hydrothermal system underground. In addition, sites of unusual surface properties such as evaporite deposits, hydrated minerals, and recent volcanic outflows may also be indicators of restricted habitats of interest. In such environments, the metabolic basis for life may be chemolithoautotrophic and independent of surface sunlight. Ultimately, to be of interest biologically, all such habitats must contain liquid water. However, it may be the observations of these other features, such as high geothermal heat flow, and not the direct detection of liquid water, that warrant further investigation.

From the point of view of Planetary Protection, the main reason for further study of the martian environment in advance of a sample return mission is to determine possible environmentally favorable locations where life might exist on Mars today. Included in this would be to search for chemical markers that indicate the presence of life. A potentially fruitful test would be a search for reduced species, such as gaseous hydrocarbons and volatile sulfides in the martian atmosphere which could be indicators of life or, also importantly, indicators of volcanic activity and the possible presence of oases. Such a search could be conducted in a way that provides spatially and temporally resolved data, thus allowing for the localization of any anomalous source region.

If life, or even a liquid water local environment, is detected on Mars during remote sensing or robotic missions or from Earth-based investigations prior to a sample return mission, this will certainly affect the site selection and strategy for the sample return.

The Apollo program is our only experience with sample return missions. During the Apollo program the return of these first extraterrestrial samples was corollary to the safe return of humans; therefore, Planetary Protection factors were largely driven by crew safety and tolerance limits. As discussed earlier, Planetary Protection procedures were not rigorously adhered to for the Apollo program (see Background). The considerations of sample and astronaut quarantine were sometimes in conflict with issues related to the health and safety of the crew, resulting in some breaches in the application of the lunar quarantine protocols. It can be argued that protocols developed for the protection of the Earth in the Apollo program were successful only because there were no organisms on the Moon, not because the protocols were rigidly employed.

On Mars the situation will be different for three reasons: 1) the first sample return will probably not be associated with humans and, therefore, crew safety and tolerance will not be overriding factors in limiting Planetary Protection requirements; 2) the question of extant life on Mars is not completely settled, and Mars is generally viewed both by the public and the scientific community as being much more likely to harbor indigenous life than was the Moon; this view could influence the perception of the dangers involved in bringing back returned samples, and may result in more rigorous treatment of the samples; and 3) there is a greatly increased public awareness of hazards to the Earth's environment.

The first sample return from Mars should be performed with robotic spacecraft. The fundamental technical reasons for this are to prevent contamination of the samples by humans and their environment during operations conducted in a manned mission, and to avoid confounding the issue of quarantine of the martian sample with the issue of contamination by humans.

A robotic sample return prior to a human mission could play an important role in reducing the concern about samples subsequently returned from Mars by humans. If there were no robotic sample return mission, then quarantine requirements would likely have to be imposed on the first human sample return mission. The cost and mission impact of implementing these Planetary Protection procedures, now involving astronauts' health and safety and life support systems, could greatly exceed the cost of a robotic sample return mission.

If the back contamination issues associated with return of samples from Mars are to be largely resolved with a robotic sample return mission, then this mission and the necessary analysis in a sample receiving facility must be in hand before a human mission is irreversibly committed to a Mars landing.

One possible scenario for the exploration of Mars involving the return of a sample would have humans go to Mars but not descend to the surface. Extensive exploration of the planet would be achieved from orbit. In this case it is possible that the first sample would be returned on such a human mission. However, the sample need not come in contact with the human astronauts and could be returned to the Earth with them but completely sealed in the original container. This would obviate the need for a separate robotic sample return mission without compromising the Planetary Protection requirements.

## Relevant Data from the Viking Mission

The search for life on Mars was one of the main objectives of the Viking Lander activities. Each of the two Viking landers carried a biology package consisting of three experiments designed to detect microbial metabolism. In addition, the Gas Chromatograph/Mass Spectrometer (GC/MS) searched for organic molecules in the soil. The results of the Viking search for life have been extensively reviewed and most investigators have concluded that the results do not indicate biological activity at the landing sites (see Klein /1, 2/ and Horowitz /3/; or for an opposing view see Levin and Straat /4, 5/).

Whether it is wise to extrapolate Viking data on the search for life on Mars to the entire planet is problematical. First, the Viking sites were chosen to ensure the safe landing of the vehicles rather than for their intrinsic value as potential sites for biology. Second, the range of microbial metabolism that was investigated in the Viking biology instruments was limited to photosynthetic uptake of CO or $CO_2$ (Pyrolytic Release Experiment, Horowitz, Hubbard, and Hobby /6/); heterotrophic decomposition of organic material (Labeled Release Experiment, Levin and Straat /7/ and Gas Exchange Experiment [GEX], Oyama and Berdahl /8/); and changes in gas composition upon humidification (Gas Exchange Experiment [GEX], Oyama, Berdahl, and Carle /9/). Other metabolic strategies may also be possible on Mars. For example, the presence of chemolithoautotrophs has been suggested by Clark /10/ and Ivanov /11/.

In considering the Viking results, it is important to keep in mind that Viking only "scratched the surface" of Mars and sampled what appeared to be a uniform aeolian mantle. It is possible that the environment just below this mantle is quite different. Before the data obtained at the Viking sites can be extrapolated to depth, further information about the nature of the sub-mantle environment is required. Of particular interest is the possible presence of organic materials in this layer and the related absence of oxidants.

While the Viking results seemed to indicate that there is no life in the martian soil, they did return interesting data on the nature of the soil. These data are not fully understood. In particular, the lack of organic material at the Viking lander sites and the presence of oxidants in the soil are major arguments against extant life on Mars. It is therefore advisable that this absence be investigated and understood. For this reason we recommend that, before a sample return mission, there be *in situ* experiments aimed at the determination of the properties of the martian soil, particularly the oxidative nature of the soil chemistry indicated by the Viking Biology experiments.

## Selection of Sites for Sample Return Missions

It was discussed earlier that further information about Mars' properties is needed before a sample return mission can be planned. In the event that the robotic precursor missions continue to suggest that Mars is totally devoid of life, and there are no locations on Mars that would offer even a possibility of life, then it would seem that the site for sample return missions, *vis-a-vis* sites for human exploration, will not be critically dependent on Planetary Protection issues. Sites could be selected to be representative, broadly speaking, of the sites where humans will land. This can be illustrated by the strong similarity between the two Viking lander sites, although they are on opposite sides of the northern hemisphere. It is possible that, from a Planetary Protection perspective, a sample return from one of these sites would be adequate to represent both sites.

If precursor robotic missions do discover that there are sites of potential biological interest on Mars, then the question of site selection for sample return is more pressing. In this case it seems likely that the Planetary Protection requirement will dictate that samples be returned from such sites, even if subsequent human missions do not elect to land at these "oasis" sites.

## General Approaches to Back Contamination Control

The available information about Mars has led most planetary scientists to conclude that the probability of extant life on Mars is exceedingly low. As a result, assessments of back contamination and of the extent of Planetary Protection measures that would be necessary in dealing with a returned sample may be colored by this premise. There is, however, no way at present to determine whether that probability is zero. Although the existence of life may be remote, its absence anywhere on the planet cannot be conclusively proven. Prudent planning dictates that additional *in situ* investigations for extant life on Mars are desirable before embarking upon sample return missions. Also, procedures employed for the return of the initial samples from Mars should be predicated on the assumption that the samples contain life. Obviously, if life is detected by robotic missions in advance of returning a sample to the Earth, the strategy for conducting a sample return mission would need to be reexamined and almost certainly there would be a call for further *in situ* examination of the martian biota before samples are returned. On the other hand, there are those who are confident that, with adequate time for planning, samples could be returned to the Earth even under these conditions, since advanced containment techniques are available that would be adequate to deal with this contingency.

Even if all data on future precursor robotic missions continue to indicate that there is no extant life on Mars, it may still be wise to include a life detection experiment as a specific part of a sample return mission and to conduct a test upon a portion of the sample that has been selected for return to the Earth. The design of such a life detection instrument poses many challenges, particularly if it is to be used to confirm a negative result. If all previous robotic missions had found no evidence for life, but such a life detection experiment yielded a positive result, it would be prudent to reconsider the remainder of the mission plan. Such reconsideration may include further *in situ* verification of the anomalous result and, if confirmed, investigation of the properties of the newly discovered life before returning the sample to Earth.

The issue of whether samples destined to be returned to the Earth should be subject to *in situ* life detection experiments before return, or whether such analyses should be performed in Earth-based laboratories, is subject to different viewpoints. Clearly, life detection experiments performed on Mars have the advantage of affording an option to delay the return of such samples until they are better characterized, if *in situ* analyses indicate the presence of life. This course also significantly minimizes potential public apprehension about the return of martian samples. On the other hand, such analyses will most certainly have limited capabilities and may yield ambiguous results. However, as additional information is obtained about specific, potentially habitable microenvironments on Mars, it should be possible to design *in situ* experiments that test for organisms hypothesized to inhabit such niches and thus reduce the chances for ambiguity. The second strategy, i.e., to conduct life detection experiments after the return of samples to the Earth, has the advantage of being able to bring to bear the latest and best technologies for the detection of organisms. This strategy would also require that the handling of the returned samples, from the sampling through the analysis, be conducted so as to avoid the loss of any labile chemical or biological species.

DeVincenzi and Klein have presented a proposal for Planetary Protection procedures for sample return missions /12/. The proposed procedures include: 1) decontamination, by some suitable method, of at least those spacecraft parts that will come in contact with the surface material, if not the whole spacecraft; 2) enclosing the spacecraft in a bio-shield to prevent re-contamination during launch and cruise; 3) sealing of the sample, preserving it at conditions as close to those on Mars as possible, and returning it to the Earth un-sterilized; 4) breaking the contact chain with the martian surface by transfer of the sample canister to another vehicle, or external decontamination of the return vehicle; and 5) return of the sample to an Earth-based containment facility where a quarantine protocol could be performed on the sample.

These procedures provide a basis for the safe return of samples from Mars. Implicit in this proposal is the requirement that the sample not be returned if there is a failure that results in the violation of procedure. To achieve this requires that: 1) the sample return vehicle must be monitored to ensure that the sample containers remain properly sealed and within design limits for temperature, pressure, and vibration, and 2) development of procedures, such as trajectory biasing, to prevent the uncontrolled return of the sample into the Earth's atmosphere, for example, due to a loss of communications with the return vehicle. These and other procedures must be identified to ensure that the sample will only return to the Earth in a controlled fashion.

Return of a Mars sample to either a lunar or orbital receiving facility is ill-advised since it is unlikely that such facilities could provide both the environmental conditions and the variety of test organisms and other materials necessary for a serious quarantine assay of the martian material. The containment of a presumably dangerous sample requires sophisticated procedures and equipment. This includes remote sample handling devices, airflow control and filtering devices, high integrity seals, and contamination containment in case of an accident. Currently, this technological and experience base exists only on the Earth in facilities developed to treat highly infectious and virulent terrestrial microorganisms. To replicate such facilities on the Moon or in orbit (either around Mars or the Earth) would pose significant challenges. It is also unlikely that the necessary experience dealing with infectious organisms could be achieved at such locations. In the confined and hermetically sealed environment of a space habitat, the difficulties of isolation and control of any accidental contamination may prove difficult to surmount. Furthermore, if a serious problem arose, the inability of the resident personnel to evacuate the facility and to enlist outside aid may compound that problem. In orbit, the virtual absence of gravity may make it difficult to control fluid samples and air flow (such as with laminar flow hoods) – procedures which are critical to maintaining quarantine in terrestrial facilities. Finally, since test organisms would be subjected to reduced gravity or weightlessness, the ability to distinguish physiological changes induced by the sample from changes known to be induced by the altered gravitational field may be impossible. When these issues are considered, it seems prudent to accept the increased risk of returning the samples directly to Earth-based laboratories.

## Back Contamination and Human Mission to Mars

If a successful and suitably extensive robotic survey of Mars and a detailed analysis of a returned sample continue to suggest that there is no life on Mars at present, then it seems reasonable to impose only minimal quarantine procedures on subsequent human exploration missions. For example, this may involve only the routine testing of new samples collected and the routine monitoring of the health of the crew.

Current Planetary Protection considerations focus on robotic missions and attempt to implement a policy of no biological contamination of Mars. Once humans land on Mars, however, this will result in biological contamination and physical alteration of the local environment. If life is detected on Mars by robotic precursors or in samples returned to the Earth, subsequent human exploration could well be restricted by policy, legal, or ethical considerations.

## Future Directions for Back Contamination Research

Many of the issues discussed require more detailed investigation. Areas where additional research is required include: 1) understanding the effects of the martian environment on terrestrial microorganisms; 2) sample handling techniques for use upon return to the Earth; 3) development of quarantine challenge tests (that use minimal sample mass) for detecting potentially harmful entities in martian material; 4) the use of bio-assays based upon cell cultures to replace whole organisms; 5) development of bio-assays for use on Mars to test the biological effects of the martian environment; e.g., the effects of the soil oxidant(s) on cells; and 6) development of experiment concepts for the detection of indigenous life in samples of martian materials.

This latter topic, life detection, warrants further discussion in view of the current assessment of the probability of finding extant life on Mars. From a Planetary Protection basis, it is prudent to test samples that may be returned to the Earth for biota even when the general prevailing scientific assessment would suggest that life is absent. For this reason life detection experiments may be a key part of a complete back contamination strategy.

## REFERENCES


/1/ Klein, H.P., "The Viking Biology Experiments on Mars," *Icarus* ***34***, pp. 666-674, 1978.

/2/ Klein, H.P., "The Viking Mission and Search for Life on Mars," *Rev. Geophys. and Space Phys.* ***17***, pp. 1655-1662, 1979.

/3/ Horowitz, N.H., *To Utopia and Back*, Freeman and Co., New York, NY, 1986.

/4/ Levin, G.V. and P.A. Straat, "Antarctic Soil No. 726 and Implications for the Viking Labeled Release Experiment," *J. Theor. Biol.* ***91***, pp. 41-45, 1981.

/5/ Levin, G.V., and P.A. Straat, "A Reappraisal of Life on Mars," IN: *The NASA Mars Conference*, D.B. Reiber, ed., A.A.S. Education, Science, and Technical Series 71, pp. 187-208, Univelt, Inc., San Diego, CA, 1988.

/6/ Horowitz, N.H., J.S. Hubbard, and G.L. Hobby, "Viking on Mars; the Carbon Assimilation Experiments," *J. Geophys. Res.* ***82***, pp. 4659-4662, 1977.

/7/ Levin, G.V., P.A. Straat, "Life on Mars? The Viking Labeled Release Experiment," *BioSystems* ***9***, pp. 165-174, 1977.

/8/ Oyama, V.I. and B.J. Berdahl, "The Viking Gas Exchange Experiment Results from Chryse and Utopia Surface Samples," *J. Geophys. Res.* ***82***, pp. 4669-4676, 1977.

/9/ Oyama, V.I., B.J. Berdahl, and G.C. Carle, "Preliminary Findings of the Viking Gas Exchange Experiments and a Model for Martian Surface Chemistry," *Nature* ***265***, pp. 110-114, 1977.

/10/ Clark, B.C., "Solar-Driven Chemical Energy Sources for a Martian Biota," *Origins of Life* ***9***, pp. 241-249, 1979.

/11/ Ivanov, M., "Potential for Searching for Chemolithoautotrophic Microorganisms on Mars," Presented at U.S./U.S.S.R. Joint Working Group Mtg., Washington, D.C., September 17, 1989.

/12/ DeVincenzi, D.L. and H.P. Klein, "Planetary Protection Issues for Sample Return Missions," *Adv. Space Res.* ***9(6)***, pp. 203-206, 1989.

# SOCIETAL AND LEGAL ISSUES

For a variety of reasons, the recommendations on back contamination, arrived at from purely technical considerations, may turn out to play a secondary role in developing the final strategy for back contamination controls. While there is no doubt that there is much to be learned from the return of martian material to the Earth, it may be naive to discount other factors including the potential public reaction to the realization of this objective. It is safe to say that there may be a lack of understanding on the part of the public at large concerning the risks of returning samples from Mars. Since the Apollo program, public attitudes about environmental matters have changed considerably - as has been demonstrated by the concerns about recombinant DNA experiments, the launching of the Galileo mission to Jupiter with its Radioisotope Thermoelectric Generator (RTG) power supplies, the Three-Mile Island accident, and public worry about technology in general. Even some scientists have joined in the public concerns about advanced technology. In turn, the attitudes of many legislators reflect these changes.

There are many national and international organizations, some highly active and well funded, on the alert for environmental mistreatment on the part of the government and the private sector. On the whole, these concerns are real, and public involvement and action are sincere and often useful. Public concern today covers a wide range of attitudes, however, and may, from time to time, become overzealous, leading to attempts to interfere with scientific and technological programs. Experience with recent conflicts between scientific advances and governmental regulations has shown also that these are often subject to sensationalism in the media with concomitant generation of additional public misunderstanding and opposition.

It can be expected that one or more environmental organizations are likely to object to any attempt by NASA to return samples from Mars to the Earth and may instigate actions challenging NASA's activities. In some cases, lawsuits may ensue, which will be both time consuming and costly. NASA should be aware of such concerns, and their possible consequences, and be prepared to deal realistically and honestly with them in advance of any sample return missions.

In addition to recognizing the importance of considering public reaction to sample return and human missions, account must also be taken of various Federal, state, and local regulatory statutes and of national and international legal restrictions that would come into play.

# LEGAL CONSIDERATIONS

Analysis of international and domestic laws makes it clear that the U.S. has inadequate Planetary Protection guidelines and regulations for certain proposed manned and unmanned space missions. For example, the states, as well as the Federal government, have jurisdiction in connection with hazardous wastes and toxic materials, and such state laws may have to be taken into consideration when locating a laboratory to handle the returned samples from Mars.

The following is a list of some U.S. Agencies which have specific relevant responsibilities spelled out in their statutes and regulations. While in each case the law was not written with hazards from other planets in mind, the goal was to protect the citizens of the U.S. or the wildlife of the U.S. (both plants and animals) from exposure to toxic or hazardous materials. Some are quite specific while some are more general; all need to be interpreted as to their applicability to extraterrestrial material, and as to how they should be implemented:

1) U.S. Public Health Service P.L. 410 (Powers of the Surgeon General)
   - CFR-41 - Regulates the quarantine of humans entering the U.S. where the concern is primarily human diseases. It also applies to interstate commerce.
2) U.S. Department of Agriculture
   - CFR-9 - Regulates the introduction and transport of viruses, sera, toxins, vectors, and organisms into the U.S.
   - CFR-7 - Regulates the introduction of plant pests and soil into the U.S.
3) U.S. Department of the Interior
   - CFR-50 - Specifies the Secretary's authority to protect and preserve the fish and wildlife and their habitat in the U.S.
4) U.S. Environmental Protection Agency
   - Various regulations exist involving environmental protection from hazardous materials and agents, requiring environmental impact analyses and statements of potentially harmful effects.

In addition to state and national concerns, international law must be considered as reflected in existing treaties such as the Outer Space Treaty as well as in any future treaties. NASA will have to consider the interpretation of terms such as "absolute liability" and "minimize risk" that exist in documents like the Charter of the United Nations, agricultural treaties, those engendered by the World Health Organization, the International Labor Organization, and international treaties on endangered species, for example.

While many treaties already exist designed to protect the Earth's environment, none currently regulate spaceflight activities. All of these documents lack specific definitions; the Outer Space Treaty /1/, for example, in alluding to Planetary Protection, refers to "harmful" and "adverse changes" without specifying what is harmful or adverse.

For legal experts to arrive at an informed position on the various legal elements of returning extraterrestrial samples, they need to understand the underlying science and risk assessments. Therefore, it is recommended that a mechanism be explored by which the legal representatives of concerned national and international agencies, and perhaps also environmental groups as well, enter into discussion of Planetary Protection issues with scientists assembled under the auspices of the National Academy of Sciences. A corollary benefit from such discussions is to be able to keep the public informed on a timely and continuous basis that NASA is aware of public concern and is actively taking steps to alleviate those concerns. This effort should be taken from the inception of a relevant Planetary Protection program and continue throughout.

## THE APOLLO EXPERIENCE

During the 1960s, in expectation of the return to Earth of the first extraterrestrial samples from the lunar surface by Apollo 11 astronauts, there were numerous scientific and technical discussions regarding the back contamination issue. These involved scientists who believed that there was absolutely no chance of indigenous life on the Moon - and thus no danger in returning lunar samples to the Earth - and those who felt that, in the absence of certainty that there was no life on the Moon, a conservative approach was necessary that would involve quarantine of the returning astronauts and testing of lunar samples for possible effects on living organisms. Despite the prevailing scientific judgement that viable lunar organisms were exceedingly unlikely, NASA took the cautious approach.

Other actions taken by NASA in preparation for returning lunar materials to the Earth included construction of a facility at the Manned Spaceflight Center (now, the Johnson Space Center, JSC), specifically designed to quarantine astronauts returning from lunar missions and to test returned lunar samples. In addition, recognizing that several other federal agencies had statutory responsibilities for the introduction and control of foreign and/or hazardous material into the U.S., an Interagency Committee on Back Contamination was established as both a planning and a "watchdog" organization. Members of this body were drawn from within the Agency and from the U.S. Departments of Agriculture and Interior, the U.S. Public Health Service, and the National Academy of Sciences.

While occasional concern was expressed by individuals in the form of complaints either of contaminating the Moon with terrestrial material or of possible back contamination and risk to terrestrial life, there was no large public outcry or organized attempt to prevent sample return during the Apollo mission.

As mentioned earlier, NASA's implementation of its lunar quarantine protocols were not entirely successful. Nevertheless, considerable experience was gained. In particular, much progress was made in developing the technology needed to protect the physical and chemical integrity of extraterrestrial materials, and this is likely to be of great importance in the future.

## GENERAL APPROACHES TO FUTURE MARS MISSIONS

While from a scientific point of view there is considerable justification for the belief that back contamination from martian material is not a hazard, this belief is by no means unanimous, even among knowledgeable scientists. It is fair to say that a large majority of scientists believes that there is no life on Mars, and that therefore precautions against back contamination are unnecessary. However, there are those who believe there may be life on Mars. Furthermore, there are those who believe that even if there is life on Mars, it would pose no hazard to anything within the Earth's biota. With that much disparity of scientific opinion, it is no wonder that the public is confused about the chances of harming the Earth inherent in returning samples from Mars, and is somewhat apprehensive. (This confused attitude was documented in a 1990 survey of non-science students at Santa Clara University in which, by a wide margin, the students believed there was no life on Mars, yet, by an even wider margin, felt that NASA must take precautions to quarantine returned martian material).

NASA must explain the differences of opinion among the scientists and also attempt to evaluate the risks to the public. This will take time and money. Public understanding and support requires NASA to be completely "up front" and forthcoming with Planetary Protection/back contamination information. The public should be satisfied that it understands the issues and that its opinions have been listened to and evaluated fairly. In other words, the public should be part of the process. Arbitrary decisions on the part of NASA will create an atmosphere of distrust, leading to potential disruption and delays with concomitant cost impacts. Information should flow in both directions. NASA should use all the communication media available to it: press, TV, educational material for schools (at all levels), workshops, lectures, special courses, exhibits, and the like. These activities should be continuing and interactive, and should start as soon as the Agency (and Congress) commits to future Mars missions (especially, but not restricted to, return sample missions). Communication of actual risk to counter sometimes inaccurately perceived risk is one of the most difficult tasks facing government and industry.

One suggestion for a potentially useful approach to interacting with the public is to prepare an exhibit on Mars exploration, including Planetary Protection concepts and problems, which could be set up at the Air and Space Museum in Washington, D.C. Variations of such an exhibit could be designed to be mobile and used at meetings, schools, other museums and appropriate public assemblages. Another approach is in the area of science education; programs for both children and adults should be developed. NASA already produces excellent educational material such as written material, films, and tapes, but more can, and should, be done.

## DEVELOPMENT OF NASA'S PLANETARY PROTECTION PROGRAM

To develop the quarantine program, NASA established a Planetary Quarantine Office in the mid-1960 s headed by a Planetary Quarantine Officer (who initially was a professional U.S. Public Health Service Officer). The Planetary Quarantine Officer was given direct access to the NASA Administrator in the event of internal non-compliance or if disagreements developed within the division(s) of NASA where there might be a conflict of interest. The office had both a research and a regulatory function. The office was provided with a staff and a budget and was charged with two major efforts: 1) to sponsor research in the area of microbiology, concentrating on the survival of microorganisms under extreme environmental conditions and, 2) to develop methodology for sample collection, decontamination of spacecraft and spacecraft components, and containment equipment.

In the same period, international agreement on Planetary Protection was sought through the Life Science Commission of COSPAR. The U.S. and U.S.S.R. agreed to a policy which required spacecraft cleaning for solar system exploration missions to targets of biological interest /2/. Although both COSPAR and NASA policy have been subsequently modified, this agreement is still in effect.

NASA has relied over the years on the National Academy of Sciences to evaluate current data on planetary environments and of the likelihood of indigenous life forms on these bodies. In the past, this group has also discussed probabilities of forward and back contamination. It is from these deliberations that a revised NASA program for Planetary Protection evolved /3/. However, over the intervening years, our knowledge of Mars has changed as has our understanding of the responses of microorganisms to environmental stresses. It is now timely to review again the whole question of Planetary Protection, including methodology to implement such a plan. Since NASA's policies in this area have been the model in the past for international agreements on Planetary Protection, through discussions with the international community within the forum of COSPAR, this review becomes especially important.

Finally, the entire matter under discussion is too complex and important to allow it to drift within the Agency. At present, there is a Planetary Protection Officer in NASA, but there is no significant Planetary Protection program. This may be understandable today where emphasis is on remote sensing spacecraft to explore the planets. However, in planning for lander and return sample missions, particularly to Mars, this situation will have to change. The Planetary Protection Officer needs the resources and authority (as discussed earlier) to do the job, a commitment from top management to support the office, and adequate time to conduct all of the planning and implementation required for success.

In addition, for the past 20 years, the Planetary Protection Officer has had other programmatic responsibilities which could easily be seen as a conflict of interest. For example, it has been customary for the Chief of the Exobiology Program also to be the Planetary Protection Officer. While this has not actually created conflicting problems in the past, it could. The desire to return samples to the Earth for scientific purposes (a goal of the Exobiology Program), could conflict with the need to quarantine those samples and restrict access to them for long periods of time (a possible goal of the Planetary Protection Officer). Indeed, NASA may have a problem in policing itself. It could be argued that even at the level of the NASA Administrator there is still a potential conflict of interest. Therefore, the possibility should be considered that an entity other than NASA should have the responsibility of policing future Planetary Protection guidelines.

## REFERENCES


/1/ "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," Article IX, U.N. Doc. A/RES/2222(XXI) January 27, 1967; TIAS No. 6347, IN: *U.S. Treaties and Other International Agreements*. ***18***, pp. 2410-2498, 1967.

/2/ Commission on Space Research (COSPAR), *Statement on the Potentially Harmful Effects of Space Experiments Concerning the Contamination of Planets*, COSPAR Information Bulletin No. 20, pp. 25 - 26, Geneva, Switzerland, 1964.

/3/ DeVincenzi, D.L. and P.D. Stabekis, "Revised Planetary Protection Policy for Solar System Exploration," *Adv. Space Res.* ***4(12)***, pp. 291-295, 1984.

# SUMMARY RECOMMENDATIONS

Summary Recommendations were developed by each sub-group. They represent an overview of the findings of each of the sub-groups and are presented here, together, for easy reference.

## FORWARD CONTAMINATION

1. Planetary Protection requirements for forward contamination should remain conservative throughout the precursor phase in the absence of additional data.
2. Entire landers should be treated to reduce initial bio-load, not just the hardware involved in the sample collection process.
3. The mission set should optimize resolution of the question of extant life on Mars during the precursor phase. Specifically, missions to optimize the characterization of sites of possible extant biology must precede the first sample return.
4. Should life be detected *in situ* or in returned samples, the sequence and objectives of subsequent missions to Mars should be reassessed.
5. Even for manned missions to Mars, some appropriate contamination control procedures may still be needed.
6. A wide range of ground-based experimental studies is needed to assess survivability, growth, and distribution of terrestrial microorganisms on Mars.
7. Consideration should be given to the construction of a Mars simulation facility in which to conduct needed research.

## BACK CONTAMINATION

1. More information is required about the martian environment before the first sample return. This information includes:
   - Search for any special sites which may contain liquid water, even transiently.
   - Search for any sites of unusual geothermal activity or surface properties.
   - Characterization of the environment below the aeolian dust mantle.

- Determination of the nature and composition of the martian soil, particularly the reactive soil chemistry indicated by the Viking Biology experiments.
- A search for reduced gases in the atmosphere.

2. The first sample return mission from Mars should be a robotic sample return.
3. Landing site selection for sample return missions should be based on both biological interest as well as potential as a human landing site.
4. Procedures developed for the robotic return of initial samples from Mars must be rigorously predicated on the assumption that there is potentially hazardous life in the samples.
5. If precursor missions indicate there is no life on Mars, it may still be wise to include life detection experiments as part of a sample return mission.
6. If there is a positive indication of life in a sample scheduled to return to the Earth, with no prior indication of martian life on other missions, then the sample return mission should be interrupted, and a reassessment should be made of the procedures for such a mission. This reassessment could result in requiring further *in situ* investigation before returning samples.
7. The following procedures for sample return missions are recommended:
   - Bio-load reduction of landed hardware
   - Use of bio-shields
   - Rigorous sealing of the sample and maintenance at near-Mars ambient conditions
   - Breaking the chain of contact with both the surface and atmospheric dust
   - Returning the sample to a containment facility on Earth (and conducting a quarantine protocol).
8. These procedures must be conducted in a fail-safe way to ensure that there is not an uncontrolled return of a sample to the Earth.
9. If all indications from precursor robotic and sample return missions suggest that there is no life on Mars at present, there may still be some minimal contamination control procedures needed on human exploration missions.
10. An on-going program of Earth-based research is indicated. Research in sample handling under Mars-like conditions is required.

## SOCIETAL AND LEGAL

1. The National Academy of Sciences should be asked by NASA to conduct a scientific and technological study of the hazards involved in return sample missions for dissemination to the public and legislators.

2. There should be a thorough study of the legal aspects involved in returning Mars samples to the Earth.
3. The public must be kept informed and become involved as plans for future Mars exploration (particularly sample return missions) unfold.
4. A significant NASA Planetary Protection Program should be re-instituted.
5. An outside committee should be established to provide continuing oversight and advice to NASA in the area of Planetary Protection.

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# BIBLIOGRAPHY

This bibliography was prepared to provide the reader with a more detailed understanding of the background and development of the problems and issues concerning Planetary Protection. It is not intended to be a definitive and complete bibliography on Planetary Protection, but rather to list key references in the program's history. Also included at the beginning of this compilation are references to two other bibliographies which were prepared by the George Washington University. These bibliographies cover the program during the period from 1966 to 1976.

With the renewed emphasis on exploration of other planetary surfaces, either with manned or unmanned landings, an understanding of the history of Planetary Protection Issues and policy, and the legal, ethical, societal, and environmental implications are essential. It is hoped that this bibliography will provide key references to begin to achieve this understanding.

## OTHER BIBLIOGRAPHIES

*Bibliography of Scientific Publications and Presentations Relating to Planetary Quarantine 1966-1971*, The George Washington University, Dept. of Medicine and Public Affairs, Biological Sciences Communication Project, Washington, D.C., April 1973.

*Bibliography of Scientific Publications and Presentations Relating to Planetary Quarantine 1972-1976*, The George Washington University, Dept. of Medical and Public Affairs, Washington, D.C., August 1977.

## ALPHABETICAL LISTING OF KEY REFERENCES

Atwood, K.C., "Sterilization and Contamination: The Nature of the Problem," IN: *Biology and the Exploration of Mars*, National Academy of Sciences/National Research Council, Washington, D.C., pp. 449-462, 1966.

Austin, P.R., "Spacecraft Sterilization," *Contamination Control* ***8***, pp. 9-12, 1969.

Bagby, J.R., H.C. Sweet, and D.L. DeVincenzi, "A Quarantine Protocol for Analysis of Returned Extraterrestrial Samples," *Adv. Space Res.* ***3***, pp. 27-34, 1983.

Bagby, Jr., J.R., *Back Contamination: Lessons Learned During the Apollo Lunar Quarantine Program*, JPL CR-560226, Jet Propulsion Laboratory, Pasadena, CA, 1975.

Barengoltz, J. and P.D. Stabekis, "U.S. Planetary Protection Program: Implementation Highlights," *Adv. Space Res.* ***3***, pp. 5-12, 1983.

Barengoltz, J.B., S.L. Bergstrom, G.L. Hobby, and P.D. Stabekis, *A Proposed New Policy for Planetary Protection*, JPL Pub. 81-90, Jet Propulsion Laboratory, Pasadena, CA, September 15, 1981.

Beller, W.S., "Soviet Spacecraft Methods Aired at COSPAR," *Missiles and Rockets* ***18***, pp. 17-18, 1966.

*Biological Contamination Control for Outbound and Inbound Planetary Spacecraft*, NASA NMI-8020.7A, NASA, Washington, D.C., 1988.

Burgess, E., *Return to the Red Planet*, Columbia University Press, New York, NY, 1990.

Clark, B.C., "Solar-Driven Chemical Energy Sources for a Martian Biota," *Origins of Life* ***9***, pp. 241-249, 1979.

Cohen, A., *Report of the 90-day Study on Human Exploration of the Moon and Mars*, NASA, Washington, D.C., 1990.

Committee on Extraterrestrial Exploration (CETEX) Report, "Contamination by Extraterrestrial Exploration," *Nature* ***183***, pp. 925-928, 1959.

Committee on Extraterrestrial Exploration (CETEX) Report, "Development of International Efforts to Avoid Contamination by Extraterrestrial Exploration," *Science* ***128***, pp. 6887-6889, 1958.

Commission on Space Research (COSPAR), *Statement on the Potentially Harmful Effects of Space Experiments Concerning the Contamination of Planets*, COSPAR Information Bulletin No. 20, pp. 25 - 26, Geneva, Switzerland, 1964.

Daspit, L., J. Stern, and J. Martin, *Lessons Learned from the Viking Planetary Quarantine and Contamination Control Experience*, NASA Contractor Report NASW-4355, NASA, Washington, D.C., September 27, 1988.

Daspit, L.P., Jr., *Planetary Quarantine Provisions*, NASA TM-7988, NASA, Langley Research Center, Hampton, VA, 1975.

DeVincenzi, D.L., "Planetary Protection Issues and the Future Exploration of Mars," *Adv. Space Res.*, in press, 1991.

DeVincenzi, D.L. and H.P. Klein, "Planetary Protection Issues for Sample Return Missions," *Adv. Space Res.* ***9(6)***, pp. 203-206, 1989.

DeVincenzi, D.L. and J.R. Bagby, eds., *Orbiting Quarantine Facility: The Antaeus Report*, NASA SP-454, NASA, Washington, D.C., 1981.

DeVincenzi, D.L. and P.D. Stabekis, "Revised Planetary Protection Policy for Solar System Exploration," *Adv. Space Res.* ***4(12)***, pp. 291-295, 1984.

DeVincenzi, D.L., P.D. Stabekis, and J.B. Barengoltz, "A Proposed New Policy for Planetary Protection," *Adv. Space Res.* ***3(8)***, pp. 13-21, 1983.

Drake, M.J., W.V. Boynton, and D.P. Blanchard, "The Case for Planetary Sample Return Missions: 1. Origin of the Solar System," *EOS* ***68***, pp. 105, 1987.

Favero, M.S., "Public Health Considerations Associated with a Mars Surface Sample Return Mission," *Life Sci. and Space Res.* ***XVI***, pp. 33-37, 1978.

Flory, D.A., and B.R. Simoneit, "Terrestrial Contamination in Apollo Lunar Samples," *Space Life Sci.* ***3***, pp. 457-468, 1972.

Gooding, J.L, M.H. Carr, and C.P. McKay, "The Case for Planetary Sample Return Missions: 2. History of Mars," *EOS* ***70***, pp. 745-755, 1989.

Hall, L.B., "NASA Requirements for the Sterilization of Spacecraft," IN: *Spacecraft Sterilization Technology*, NASA SP-108, pp. 25-29, NASA, Washington, D.C., 1974.

Hall, L.B., "Ten Years of Development of the Planetary Quarantine Program of the United States," *Life Sci. and Space Res.* ***XII***, pp. 185-197, 1974.

Hall, L.B., "The Importance of Sterilization Techniques in Space Exploration," IN: *Sterilization Techniques for Instruments and Materials as Applied to Space Research*, P.H.A. Sneath, ed., COSPAR Technical Manual No. 4, pp. 3-18, 1968.

Hall, L.B., ed., *Planetary Quarantine: Principles, Methods, and Problems*, Gordon and Breach Science Publishers, New York, NY, 1971.

Hall, L.B. and C.W. Bruch, "Procedures Necessary for the Prevention of Planetary Contamination," *Life Sci. and Space Res.* ***III***, pp. 48-62, 1965.

Hochstein, L.I., K.A. Kvenvolden, and D.E. Philpott, *The Effect of Sterilization on Biological, Organic Geochemical and Morphological Information in Natural Samples with Reference to a Mars Surface Sample Return Mission*, NASA TM-X72883, NASA, Washington, D.C., 1974.

Hoffman, A.R., W. Stavro, L.W. Miller, and D.M. Taylor, "Terrestrial Quarantine Considerations for Unmanned Sample Return Missions," *Life Sci. and Space Res.* ***XII***, pp. 215-220, 1974.

Horowitz, N.H., J.S. Hubbard, and G.L. Hobby, "Viking on Mars; the Carbon Assimilation Experiments," *J. Geophys. Res.* ***82***, pp. 4659-4662, 1977.

Horowitz, N.H., *To Utopia and Back*, Freeman and Co., New York, NY, 1986.

Huguenin, R.L., K.L. Miller, and S.B. Leschine, "Mars: A Contamination Potential," *Adv. Space Res.* ***3***, pp. 35-38, 1983.

Ivanov, M., "Potential for Searching for Chemolithoautotrophic Microorganisms on Mars," Presented at U.S./U.S.S.R. Joint Working Group Mtg., NASA, Washington, D.C., September 17, 1989.

Johnston, R.S., *Headquarters Flight Readiness Review, Apollo 11, Back Contamination*, NASA TM-X62647, NASA Manned Space Flight Center, Houston, TX, June 1969.

Johnston, R.S., *Report on the Status of the Apollo Back Contamination Program*, NASA TM X-72278, NASA, Washington, D.C., June 1969.

Jukes, T.H., "Evolution and Back Contamination," *Life Sci. and Space Res.* ***XV***, pp. 9-14, 1977.

Kemmerer, Jr., W.W., J.B. Hammack, and R.S. Johnston, *Back Contamination Mission Rules (Recovery to Lunar Receiving Lab)*, NASA TM-X69929, NASA, Washington, D.C., May 1969.

Klein, H.P., "The Viking Biology Experiments on Mars," *Icarus* ***34***, pp. 666-674, 1978.

Klein, H.P., "The Viking Mission and Search for Life on Mars," *Rev. Geophys. and Space Phys.* ***17***, pp. 1655-1662, 1979.

Lederberg, J. and C. Sagan, "Relationship of Planetary Quarantine to Biological Search Strategy," *Life Sci. and Space Res.* ***VI***, pp. 136-145, 1968.

*Lessons Learned from the Viking Planetary Quarantine and Contamination Control Experience*, NASA Contractor Report NASW-4355, NASA, Washington, D.C., 1990.

Levin, G.V. and J.M. Hall, "Quarantine Concepts for a Mars Return Sample Mission," *Life Sci. and Space Res.* ***XV***, pp. 15-19, 1978.

Levin, G.V. and P.A. Straat, "Antarctic Soil No. 726 and Implications for the Viking Labeled Release Experiment," *J. Theor. Biol.* ***91***, pp. 41-45, 1981.

Levin, G.V., and P.A. Straat, "A Reappraisal of Life on Mars," IN: *The NASA Mars Conference*, D.B. Reiber, ed., A.A.S. Education, Science, and Technical Series 71, pp. 187-208, Univelt, Inc., San Diego, CA, 1988.

Levin, G.V., P.A. Straat, "Life on Mars? The Viking Labeled Release Experiment," *BioSystems* ***9***, pp. 165-174, 1977.

Maag, C.R., ed., *Spacecraft Contamination Environment*, Proceedings of the International Society for Optical Engineering, SPIE Vol. 338, 131 p, Arlington, VA, May 1982.

Mahoney, T., *Organization Strategies for the Protection Against Back Contamination*, NGL 24-005-160 Final Report, Univ. of Minnesota, MN, June, 1976.

Margulis, L., H.O. Halvorson, J. Lewis, and A.G.W. Cameron, "Limitations to Growth of Microorganisms on Uranus, Neptune, and Titan," *Icarus* ***30***, pp. 793-808, 1977.

Margulis, L., H.O. Halvorson, J. Lewis, and A.G.W. Cameron, "Some General Principles of Planetary Quarantine Leading to an Assessment of the Limitations to Growth of Microorganisms on Uranus and Neptune," *Life Sci. and Space Res.* ***15***, pp. 101-106, 1977.

*Mars Observer Planetary Protection Plan*, JPL Report D-2749, Jet Propulsion Laboratory, Pasadena, CA, October 1985.

*Mars Surface Sample Return Quarantine Planning Study, Final Presentation*, JPL Pub. 760-158, Jet Propulsion Laboratory, Pasadena, CA, November 17, 1976.

McKay, C.P. and W.L. Davis, "Planetary Protection Issues in Advance of Human Exploration of Mars," *Adv. Space Res.* ***9***, pp. 197-202, 1989.

McKay, C.P., "Does Mars Have Rights? An Approach to the Environmental Ethics of Planetary Engineering," IN: *Moral Expertise*, D. MacNiven, ed., Routledge, London, pp. 184-197, 1990.

Newell, H.E., "The Role and Responsibility of NASA in Relation to Spacecraft Sterilization," IN: *Spacecraft Sterilization Technology*, NASA SP-108, pp. 11-18, NASA, Washington, D.C., 1966.

*Outbound Planetary Biological and Organic Contamination Control: Policy and Responsibility*, NASA NPD-8020.10, NASA, Washington D.C., August 1972.

*Outbound Spacecraft: Basic Policy Relating to Lunar and Planetary Contamination Control*, NASA NPD-8020.7, NASA, Washington, D.C., September 6, 1967.

Oyama, V.I. and B.J. Berdahl, "The Viking Gas Exchange Experiment Results from Chryse and Utopia Surface Samples," *J. Geophys. Res.* ***82***, pp. 4669-4676, 1977.

Oyama, V.I., B.J. Berdahl, and G.C. Carle, "Preliminary Findings of the Viking Gas Exchange Experiments and a Model for Martian Surface Chemistry," *Nature* ***265***, pp. 110-114, 1977.

Phillips, C.R. and R.K. Hoffman, "Sterilization of Interplanetary Vehicles," *Science* ***132***, pp. 991-995, 1960.

Phillips, C.R., *The Planetary Quarantine Program, Origins and Achievements 1956-1973*, NASA SP-4902, NASA, Washington, D.C., 1974.

Phillips, G.B., "Back Contamination," *Environmental Biology and Medicine 1*, pp. 121-160, 1971.

Pickering, J.E. and G.B. Phillips, "Back Contamination," *Contamination Control 7*, pp. 19-23, 1968.

*Planetary Sample Rapid Recovery and Handling*, Eagle Engineering Report No. 85-105, NASA Johnson Space Center, Houston, TX,1977.

Puleo, J.R., G.S. Oxborrow, and R.C. Graves, "Microbial Contamination Detected on the Apollo 9 Spacecraft," IN: *1969 Proceedings Eight Annual Technical Meeting and Exhibit, American Association for Contamination Control*, Boston, MA, May 1969.

Puleo, J.R., G.S. Oxborrow, N.D. Fields, and H.E. Hall, "Quantitative and Qualitative Microbiological Profiles of the Apollo 10 and Apollo 11 Spacecraft," *Applied Microbiology 3*, pp. 384-389, 1970.

Puleo, J.R., N.D. Fields, B. Moore, and R.C. Graves, "Microbial Contamination Associated with the Apollo 6 Spacecraft During Final Assembly and Testing," *Space Life Sci. 2*, pp. 48-56, 1970.

Puleo, J.R., N.D. Fields, S.L. Bergstrom, G.S. Oxborrow, P.D. Stabekis, and R.C. Koukol, "Microbiological Profiles of the Viking Spacecraft," *Applied and Environmental Microbiology* ***33(2)***, pp. 379-384, 1977.

Puleo, R.R., G.S. Oxborrow, N.D. Fields, C.M. Herring, and L.S. Smith, "Microbiological Profiles of Four Apollo Spacecraft," *Applied Microbiology 6*, pp. 838-845, 1973.

*Quarantine Provisions for Unmanned Extraterrestrial Missions*, NASA NHB-8020.12A, NASA, Washington, D.C., February 1976.

Reynolds, G.H. and R.P. Merges, *Outer Space: Problems of Law and Policy*, Westview Press, Boulder, CO, 1989.

Reynolds, O.E. and O.W. Nicks, "NASA Program Scope and Definition," IN: *Spacecraft Sterilization Technology*, NASA SP-108, pp. 19-39, NASA, Washington, D.C., 1966.

Robinson, G.S., "Earth Exposure to Martian Matter: Back Contamination Procedures and International Quarantine Regulations," IN: *Proceedings of the 18th Colloquium on the Law of Outer Space*, Rothman and Co., pp. 134-149, 1976.

Rummel, J.D., "Planetary Protection Policy Overview and Application to Future Missions," *Adv. Space Res.* ***9***, pp. 181-184, 1989.

Sagan, C. and J. Lederberg, "The Prospects for Life on Mars: A Pre-Viking Assessment," *Icarus* ***28***, pp. 291-300, 1976.

Sagan, C. and S. Coleman, "Spacecraft Sterilization Standards and Contamination of Mars," *Astronaut. Aeron.* ***3***, pp. 22, 1965.

Schalkowsky, S., L.B. Hall, and R.C. Kline, "Potential Effects of Recent Findings on Spacecraft Sterilization Requirements," *Space Life Sci.* ***4***, pp. 520-530, 1969.

Sharp, J.C., "Manned Mars Mission and Planetary Quarantine Considerations," IN: *Manned Mars Missions, Working Group Papers*, NASA TM-002 II, pp. 550-555, NASA, Washington, D.C., June 1986.

Space Science Board Committee on Planetary Biology and Chemical Evolution, *Recommendations on Quarantine Policy for Mars, Jupiter, Saturn, Uranus, Neptune, and Titan*, National Academy of Sciences, Washington, D.C., 1978.

Space Science Board Committee on Planetary Biology and Chemical Evolution, *Review of the Sterilization Parameter: Probability of Growth (Pg)*, National Academy of Sciences, Washington, D.C., December 4, 1970.

Stabekis, P.D., "Review of Post Viking Planetary Protection Requirements for Mars," Presented to the JPL MSSR Panel on Planetary Protection, Jet Propulsion Laboratory, Pasadena, CA, November 15, 1968.

Stabekis, P.D. and D.L. DeVincenzi, "Planetary Protection Guidelines for Outer Planet Missions," *Life Sci. and Space Res.* ***XVI***, pp. 39-44, 1978.

Steg, S.E. and R.C. Cornell, "Biological Losses and the Quarantine Policy for Mars," *Space Life Sciences* ***1***, 514-519, 1969.

Sterns, P.M. and L.I. Tennen, "Current U.S. Attitude Concerning Protection of the Outer Space Environment," IN: *Proceedings of The 27th Colloquium on the Law of Outer Space*, pp. 398, 1985.

Sterns, P.M. and L.I. Tennen, "Protection of Celestial Environments through Planetary Quarantine Requirements," IN: *Proceedings of the 23rd Colloquium on the Law of Outer Space* ***107***, pp. 112-114, 1981.

Sterns, P.M. and L.I. Tennen, "Preserving the Pristine Environments: The Planetary Protection Policy," Presented at the IAA/IAF Academy Symposium, October 1989.

Sweet, H.C., J.R. Bagby, and D.L. DeVincenzi, "The Antaeus Project: An Orbital Quarantine Facility for Analysis of Planetary Return Samples," *Adv. Space Res.* ***3***, pp. 23-26, 1983.

Taylor, D.M., R.M. Berkman, and N. Divine, "Consideration of Probability of Bacterial Growth for Jovian Planets and their Satellites," *Life Sci. and Space Res.* ***XIII***, pp. 111-118, 1972.

"Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," Article IX, U.N. Doc. A/RES/2222(XXI) January 27, 1967; TIAS No. 6347, IN: *U.S. Treaties and Other International Agreements* ***18***, pp. 2410-2498, 1967.

Vashkov, V.I., N.V. Ramkova, G.V. Scheglova, L.Z. Skala, and A.G. Nekhorosheva, "Verification of the Efficiency of Spacecraft Sterilization," *Life Sci. and Space Res.* ***XII***, pp. 119-202, 1974.

Werber, M., *Objectives and Models of the Planetary Quarantine Program*, NASA SP-344, NASA, Washington, D.C., 1975.

Wolfson, R.P., *MSSR Quarantine Requirements, Task Planning Report*, Prepared for Jet Propulsion Laboratory by Exotech Research and Analysis, July 29, 1976.

Wolfson, R.P., *Post Viking Planetary Protection Requirements Study*, NASA CR-155585, Prepared for Jet Propulsion Laboratory, Pasadena, CA, August 31, 1977.

Wooley, B.C. *Apollo Experience Report: Protection of Life and Health*, NASA TN-D6856, NASA, Washington, D.C., June 1972.

Wooley, B.C., "Containment and Biological Evaluation Procedures for Returned Mars Samples," *Life Sci. and Space Res.* ***XV***, pp. 3-7, 1977.

Young, R.S. and D.L. DeVincenzi, "From Mars with Love," *Science* ***18***, pp. 495-501, 1974.

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# FINAL AGENDA

## WEDNESDAY, MARCH 7, 1990

| | | | |
|---|---|---|---|
| 8:30 am | Objectives, Logistics, and Opening Remarks | | D. DeVincenzi<br>H. Klein<br>J. Bagby |
| 9:00 | Application of NASA's Planetary Protection Policy to Future Mars Missions | | J. Rummel |
| 9:30 | SESSION I: Planetary Protection on Past Missions | | J. Bagby, Chair |
| | • Planetary Protection Implementation on Soviet Mars Missions | H. Klein | |
| | • Summary of Viking Planetary Protection Implementation | L. Daspit | |
| | • Lessons Learned During the Apollo Program | J. Bagby | |
| 10:30 | Break | | |
| 10:45 | SESSION II: Legal and Societal Planetary Protection Issues | | J. Bagby, Chair |
| | • Potential Public Reaction | M. Race | |
| | • Legal Basis for Planetary Protection | G. Robinson | |
| | • Panel Discussion I | | |
| 12:30 pm | Lunch | | |
| 1:30 | SESSION III: Environment of Mars | | H. Klein, Chair |
| | • Evolution of Mars | R. Greeley | |
| | • State and Distribution of Volatiles on Mars | A. Zent | |
| | • Possibility of Chemical Evolution and the Origin of Life on Mars | H. Klein | |
| | • Panel Discussion II | | |
| 3:45 | Break | | |
| 4:00 | Human Exploration of Mars: Mission Development and Science Program | | N.A. Budden |
| 4:30 | Strawman Planetary Protection Guidelines for the Human Exploration of Mars | | D. DeVincenzi |
| 5:15 | Adjourn | | |

## THURSDAY, MARCH 8, 1990

| | | |
|---|---|---|
| 8:30 am | Sub-group Meetings | |
| | • Forward Contamination | P. Stabekis, Chair |
| | • Back Contamination | C. McKay, Chair |
| | • Legal and Societal Implications | R. Young, Chair |
| 12:00 | Lunch | |
| 1:00 pm | Sub-group Meetings (cont.) | |
| 5:00 | Adjourn | |

## FRIDAY, MARCH 9, 1990

| | | |
|---|---|---|
| 8:30 am | Human Exploration Initiative Status | C. Pilcher |
| 9:00 | SESSION IV: Sub-group Reports | D. DeVincenzi, Chair |
| | • Forward Contamination | P. Stabekis, Chair |
| | • Back Contamination | C. McKay, Chair |
| | • Legal and Societal Implications | R. Young, Chair |
| 10:30 | Break | |
| 10:45 | Open Discussion of Workshop Conclusions, Recommendations, and Planetary Protection Guidelines | D. DeVincenzi, Chair |
| 12:30 | Lunch; Workshop Adjourn | |
| 1:30 pm | Executive Session | |
| 5:00 | Adjourn | |

# GLOSSARY OF ACRONYMS

| | |
|---|---|
| CETEX | Committee on Extraterrestrial Exploration |
| CFR | Code of Federal Regulations |
| CM | Command Module |
| COSPAR | Commission on Space Research |
| CP | Conference Publication |
| GC/MS | Gas Chromatograph/Mass Spectrometer |
| GEX | Gas Exchange Experiment |
| JPL | Jet Propulsion Laboratory |
| JSC | Johnson Space Center |
| LEM | Lunar Excursion Module |
| MESUR | Mars Environmental Survey |
| MO | Mars Observer |
| MSSR | Mars Surface Sample Return |
| NASA | National Aeronautics and Space Administration |
| NHB | NASA Hand Book |

| | |
|---|---|
| NMI | NASA Management Instruction |
| NPD | NASA Policy Directive |
| NRC | National Research Council |
| PP | Planetary Protection |
| RTG | Radioisotope Thermoelectric Generator |
| SEI | Space Exploration Initiative |
| TIAS | Treaties and Other International Acts Series |
| TM | Technical Memorandum |
| TN | Technical Note |

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A primary scientific theme for the Space Exploration Initiative (SEI) is the search for life, extant or extinct, on Mars. Because of this, concerns have arisen about Planetary Protection (PP), the prevention of biological cross-contamination between Earth and other planets during solar system exploration missions. A recent workshop assessed the necessity for, and impact of, PP requirements on the unmanned and human missions to Mars comprising the SEI. The following ground-rules were adopted: 1) Information needed for assessing PP issues must be obtained during the unmanned precursor mission phase prior to human landings; 2) Returned Mars samples will be considered biologically hazardous until proven otherwise; 3) Deposition of microbes on Mars and exposure of the crew to martian materials are inevitable when humans land; and, 4) Human landings are unlikely until it is demonstrated that there is no harmful effect of martian materials on terrestrial life forms. These ground-rules dicated the development of a conservative PP strategy for precursor missions. Key features of the proposed strategy include: 1) To prevent forward-contamination, all orbiters will follow Mars Observer PP procedures for assembly, trajectory, and lifetime. All landers will follow Viking PP procedures for assembly, microbial load reduction, and bio-shield; and, 2) To prevent back-contamination, all sample return missions will have PP requirements which include fail-safe sample sealing, breaking contact chain with the martian surface, and containment and quarantine analysis in Earth-based laboratory. In addition to deliberating on scientific and technical issues, the workshop made several recommendations for dealing with forward and back-contamination concerns from non-scientific perspectives.

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