

# Planetary Protection Considerations For Future Exploration

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*Abstract*—Since 1967, a policy has been in place to control contamination of planets from both terrestrial organisms and organic constituents. The policy, implemented by the National Aeronautics and Space Administration, lays out a framework of guidelines for implementing future missions. During the course of structuring an active program to explore our solar system, it has become increasingly apparent that planetary protection factors will have a significant impact on future missions design, cost and complexity.

For some missions, the microbial load on the hardware must be limited during manufacturing and building processes, and controlled during assembly, test and launch operations. These limitations can be assured by adopting strict clean room standards including personnel and operational procedures, re-cleaning to maintain cleanliness during pre-launch processing of hardware with appropriate fluids, and possible terminal sterilization. For other missions, one must examine the hazards of accidental impact and all other events that may release organisms. Various constraints on flight trajectories, orbital altitudes and dwell times must be considered and implemented during the design phase of the mission.

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## 1. INTRODUCTION

The National Aeronautics and Space Administration has had a policy in place since 1967 to control contamination of planets by terrestrial microorganisms and organic constituents during planetary exploration [1]. The purpose of the planetary protection policy is to preserve conditions for future biological and organic exploration of planets and other solar system objects and to protect Earth and its biosphere from potential contamination by extraterrestrial sources.

The current policy adopted by NASA accomplishes three things: 1) It preserves conditions on the planet for the future conduct of missions, 2) It meets signatory agreements on the protection of planets from potential hazards, and 3) It protects the Earth's biosphere from the possibility of back contamination.

Our search for extraterrestrial life in the last 40 years has focused on Mars. As a result of the scientific findings of the planetary missions to Mars, the development and implementation of planetary protection policies have evolved with our increasing understanding of the martian environment and its biological potential. Through the Committee on Space Research (COSPAR) of the International Council of Scientific Unions, review and analysis of the policy have been ongoing.

The Viking experience illustrates the nature of the impact planetary protection has on a flight project, and how it might be effectively addressed. Our updated understanding of the ability of Mars to support terrestrial life has contributed to a revision of policy that distinguishes between missions with and without life-detection experiments and lessens the impact of planetary protection on future missions.

NASA's Galileo spacecraft made several close passes by Europa resulting in new findings about the jovian moon, and interest in Europa has been intensified by the fact that an ocean of liquid water may lie beneath its surface covering of ice. Life could exist within or below Europa's icy shell.

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## 2. BACKGROUND

Early discussions regarding the need for protecting the planets began soon after the successful launch of Sputnik in 1957, and in 1964 the international community, through the Committee on Space Research (COSPAR) of the International Council of Scientific Unions, adopted a set of recommendations [2] for the protection of the planets and for the reduction of the numbers of microorganisms on spacecraft.

In 1967, the concern for protection of the planets was included in Article IX of the UN Space Treaty [3]. As a signatory to that treaty, the United States accepted the declaration that "States Parties to the treaty shall pursue studies of outer space . . . 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 symposium devoted to the subject of heat treatment of spacecraft and published a set of quantitative guidelines for implementing planetary protection. NASA adopted the guidelines, established a Planetary Protection Office, and issued a directive based on the use of probabilistic models. This directive was revised in 1984 to eliminate the blanket quantitative guidelines from the policy statement [4], but sustained the commitment by space-faring nations to preserve the natural planetary environments.

Understanding the origin and evolution of life is an important goal of NASA. Searching for life on other planets where physical, hydrologic and geochemical properties might favor the existence of replicating systems like those found on Earth is one approach toward accomplishing that goal. Although the search for existing or ancient life is challenging, knowledge gathered from Mariner, Viking, Mars Global Surveyor, and Mars Odyssey leads us to determine that Mars has experienced dynamic interactions between its atmosphere, surface, and interior that can be related to water, therefore making it an attractive target for understanding life, its origins and its diversity.

Observations of Europa indicate geologic activity in the recent past and suggest that liquid water might exist beneath a surface ice shell some 10 to 170 km thick. Because the Space Studies Board (SSB) is not able to reach complete agreement on the central issue of planetary protection standards for future missions to Europa in light of these observations [5], the very first mission to Europa will likely be subject to meeting the highest reasonable level of safeguard. These safeguards must be undertaken to protect the scientific integrity of future studies of Europa's biological potential and to protect against potential harm to european organisms.

Recently, the Galileo spacecraft purposely was put on a collision course with Jupiter to eliminate any chance of an unwanted impact with Jupiter's satellite Europa. With its onboard propellant nearly depleted, controlling Galileo's trajectory and any potential contamination of Europa would not be possible. To safeguard the scientific integrity of future studies and to protect against potential harm to european organisms, the decision was made to guide Galileo into Jupiter's atmosphere where it would harmlessly disintegrate.

### 3. PLANETARY PROTECTION AND U.S. MISSIONS

The basic NASA planetary protection policy currently in effect is formulated to preserve science, meet our international treaty agreement by protecting the planets (including Earth) from potential hazards, and to protect the planets by imposing controls on potential contamination carried by spacecraft. NASA made significant changes to its policy in 1990 after asking the Space Studies Board of the National Research Council to reconsider the problem of forward contamination of Mars by landers [6]. The quantitative method used for the Viking mission is replaced in current policy with controls based on five categories of planetary missions.

NASA Policy Guide, NPG 8020.12B, "Planetary Protection Provisions for Robotic Extraterrestrial Missions," [7] sets forth the requirements, consistent with the COSPAR [11] objectives and SSB [6] recommendations, applicable to robotic planetary flight projects and includes implementation based on the nature of the mission and of the target planet. Each mission falls into one of five categories as shown in Table 1.

Category I missions are aimed at targets of no direct exobiological interest, e.g. the Sun or moon, and relieve a project of all further planetary protection requirements. Categories II, III and IV include flybys, orbiters, landers and probes sent to targets of increasing exobiological interest.

Because there is only a remote chance that contamination carried by a spacecraft would compromise future exploration, there are no formal implementation requirements for category II. The mission needs only to be conducted as planned to minimize the likelihood of accidental impact, and prepare simple documentation.

Category III missions must avoid direct contact with the target planet since the mission investigates a body of chemical evolution and/or origin of life interest and could jeopardize future biological experimentation. The practice of contamination control through the use of clean rooms is imposed on category III flyby and orbiter missions. Orbiter spacecraft that achieve bioloads equal to the Viking pre-sterilization bioload will not be required to meet impact or orbital lifetime requirements. A category III orbiter that does not meet the Viking pre-sterilization bioload is required to meet a probability of impact requirement.

**Table 1. Planetary Protection Mission Categories**

<i>Planet Priorities</i>		<i>Mission Type</i>	<i>Mission Category</i>
A	Not of direct interest for understanding the process of chemical evolution. No protection of such planets is warranted and no requirements are imposed.	Any	I
B	Of significant interest relative to the process of chemical evolution, but only a remote chance that contamination by spacecraft could jeopardize future exploration.	Any	II
C	Of significant interest relative to the process of chemical evolution and/or the origin of life or for which scientific opinion provides a significant chance of contamination which could jeopardize a future biological experiment.	Flyby, Orbiter	III
		Lander, Probe	IV
All	Any solar system body	Earth-Return	V

Category IV missions are of significant biological interest relative to the process of chemical evolution and/or the origin of life. Through COSPAR [6], new information gained from Viking was reviewed and analyzed and resulted in the development of

category IVa and category IVb. Category IVa missions are comprised of a lander or probe but do not carry life-detection experiments. It was determined that these missions should not require full sterilization as Viking had, but instead these spacecraft should be assembled in clean rooms and the components should be cleaned to reduce surface organics and the microbial load to the same levels that were obtained for Viking before terminal sterilization.

It was further determined that landers with life-detection experiments on board should be subject to at least Viking-level sterilization procedures. Category IVb landers or probes carry life-detection experiments and require a complete system sterilization. Table 2 shows the major differences between categories IV A and IV B.

Category V is the most stringent planetary protection control, and is reserved for Earth-return missions. Protection of the terrestrial system, the Earth and the moon, are the concern for category V missions. If a mission is targeted to a solar system body that the SSB and COSPAR have determined has no indigenous life, a subcategory of “unrestricted Earth return” is defined. Otherwise, strict Earth-return measures are imposed on category V missions.

**Table 2. Differences in Mission Categories IVa and IVb.**

Category IVa	Category IVb
1. Requires bioburden reduction.	1. All of category IVa requirements.
2. No sterilization required.	2. Terminal sterilization required.
3. <300 spores/m <sup>2</sup> and <300,000 spores per landing event.	3. <30 organisms (vegetative and spore-formers) per landing event.
4. Assay process selects for spore-forming cells only.	4. Vegetative and spore-forming cells selected/ counted.
5. No probability calculations.	5. Less than or equal to 1% probability of a single, viable earth organism contaminating planetary rock/soil sample.

After asking the Space Studies Board to reconsider the problem of forward contamination of Mars by landers, NASA made significant changes to its policy in 1990 [8]. The recommendations of the SSB carried long-range strategic implications for the exploration of Mars. Since local contamination of a target body is expected around a non-sterilized spacecraft, it is extremely important to maximize spacecraft cleanliness so as to: 1) minimize the introduction of foreign material into any site that might be the focus of subsequent investigations, and 2) minimize the contamination of on-board devices that are extremely sensitive to organic and biological contamination.

These revised requirements have been imposed on all recent outbound Mars missions. Mars Observer, launched in 1992, and Mars Global Surveyor, launched in 1996, were both category III missions. Placing these orbiting spacecraft in this category clearly stated the exobiological interest in Mars and its potential contamination, and subjected the spacecraft to clean room assembly, trajectory biasing and an inventory of the launched bioload. Mars Pathfinder, a category IVa lander mission, was subjected to clean room assembly with treatment for bioload reduction and an inventory of the launched bioload. Neither the more recent Mars '98 mission, which consisted of both an orbiter and a lander, the Mars Odyssey orbiter, nor the Mars Exploration Rover mission was categorized higher than a category IVa.

#### 4. VIKING: LESSONS LEARNED

It has been more than 25 years since Viking was launched to directly seek evidence of biological activity in the upper 10cm of the surface of Mars. The Viking landers were the first planetary spacecraft designed to be fully sterilizable and to carry insurance of that cleanliness into space. Unique system components to help assure the integrity of the system after heat treatment were incorporated from the very beginning. At a time when the state-of-the-art technology and heat were still incompatible, the Project frontally confronted the issues. Viking was the trailblazer for future missions to planets of biological significance, and this experience is still applicable to future missions.

There is consistent agreement among the scientific community that dry-heat sterilization is the best way to achieve the reduction of bioloads required to launch a lander to Mars [9] or any other body of biological interest. Although new methods of sterilization may become available, the reality of it is that the problems, challenges and major decisions associated with heat sterilization of the Viking lander are known and will likely be similar for future missions.

The Viking mission was conceived and designed in the late 1960's and landed two fairly sophisticated spacecraft on the surface of Mars. Some of the lessons learned from the Viking experience include:

*Planetary protection is an important issue and must not be taken lightly.* Viking emphasized the search for life on Mars and carried three experiments designed to look for evidence of biological activity in the surface material. Clearly, the instruments were susceptible to contamination from sources on Earth and needed to be protected to ensure that the data returned from the surface of Mars were not corrupted. Scientific results from Viking, Mars Global Surveyor and Mars Odyssey lead to an additional concern as evidenced by the NRC's Space Studies Board [10] that states, "Although current evidence suggests that the surface of Mars is inimical to life as we know it, there remain plausible scenarios for extant microbial life on Mars—for instance, in possible hydrothermal oases or in subsurface regions." Planetary protection has the backing of the world's scientific community.

*NASA, in the 1960's, accepted the planetary protection requirements and initiated policies and procedures necessary to implement them on flight projects to planets of biological interest.* It was necessary to translate general requirements into specific ones, and to determine acceptable approaches that the Project could implement. A great deal of research was done in university and government laboratories to find methods for cleaning and sterilizing spacecraft. Survivability studies were conducted on microorganisms under simulated martian conditions, and it was concluded that the biological instrumentation was the system most sensitive to contamination.

*Top management supported the implementation of the planetary protection requirements.* The management and technical teams anticipated an impact on the Viking Project and assigned a high priority to technical issues arising from planetary protection. This is an important lesson learned associated with a successful planetary protection strategy. The top-level management at NASA Headquarters, the Centers and the prime contractor supported and implemented the details of planetary protection requirements throughout all disciplines of the Project, and everyone understood that any problems were to be taken to the management so that the appropriate resources could be brought to bear on the issue. This approach resulted in a technically acceptable solution in a timely manner.

If one were to study a single case to demonstrate this point, it could be how the spacecraft parts were qualified. The qualification program on Viking was driven by meeting the heat requirement imposed by planetary protection, but its imposition was so successful that some believe it may have led to reduced costs, improved reliability margin, and enhanced relationships between the elements of the Project.

## 5. CONSIDERATIONS FOR FUTURE MISSIONS

Experiences from previous planetary missions to planets of biological interest reveal what planetary protection constraints might be imposed on future missions. Currently, the NASA mission model includes missions to two bodies that may have experienced prebiotic chemical evolution or that may have developed life, i.e. Mars and Jupiter's satellite, Europa. The Space Studies Board, having earlier considered the exploration of both of these bodies [5,6], recommended planetary protection policy for upcoming missions, and further recommended what knowledge must be gained before making recommendations regarding contamination of Earth from Mars (back contamination).

### *Missions to Mars*

If all goes as planned, the 2005 Mars Reconnaissance Orbiter (MRO) will narrow the investigative focus into localities identified from previous missions and search for the most compelling environmental indicators suitable for sustaining life. MRO will be followed by the Mars Science Laboratory (MSL) in 2009. MSL will traverse many kilometers and operate for months to explore the most promising sites through a suite of experiments designed to answer questions about biological processes. As we advance in our strategy to explore Mars through in-situ analysis, future missions will carry with them the potential for sterilization of the entire landed system.

Today, planetary protection requirements are being assessed and defined by newly acquired knowledge of organisms living in extreme environments on our planet, the increasing sensitivity of instrumentation associated with life detection experiments,

and the probability that conditions needed to support life may have existed in the past on Mars. In a review of the forward contamination of Mars in 1992, the SSB task group concluded [6]:

“that the probability of growth of a terrestrial organism on present-day Mars is essentially zero. However, the task group recommends bioload reduction for anything sent to the martian surface. Major advances in our ability to detect cellular material have occurred over the last decade, and future advances will undoubtedly follow. Reducing contamination of the planet by reducing the bioload on landed vehicles will minimize the chances of jeopardizing future experiments designed to detect material of possible biological origin.”

In October of 2002, COSPAR approved policy [11] that reflects a further updated state of scientific knowledge. The basic premise of earlier policy that scientific investigations should not jeopardize future science at a planet of biological interest still remains, and the policy continues to be implemented based on certain space mission/target planet combinations. In addition to meeting all of the requirements of category IVa, missions that investigate “special regions” of Mars are assigned to a new category IVc. Special regions of Mars are areas within which terrestrial organisms are likely to propagate, or regions that are interpreted to have a high potential for the existence of extant martian life. The recommendation will result in the reduction of contamination by terrestrial organic matter and/or microorganisms deposited at the landing site:

*Case 1:* If the landing site is within the special region, the entire landed system shall be sterilized at least to the Viking post-sterilization bioload levels.

*Case 2:* If the special region is accessed through horizontal or vertical mobility, either the entire landed system shall be sterilized to the Viking post-sterilization bioload levels, or the systems which directly contact the special region shall be sterilized to these levels, and a method of preventing their recontamination prior to accessing the special region shall be provided.

If an off-nominal condition (such as a hard landing) would cause a high probability of inadvertent biological contamination of the special region by the spacecraft, the entire landed system must be sterilized to the Viking post-sterilization bioload levels.

Contamination at a site by microorganisms or organic residues carried on spacecraft must be reduced to the greatest extent possible. Requirements imposed on Projects will undoubtedly be driven by the nature and sensitivity of the instruments.

#### *Missions to Europa*

The findings from NASA’s Galileo mission has intensified interest in Jupiter’s moon Europa. The SSB Task Group on the Forward Contamination of Europa considered whether life might already be present on Europa or whether it could be introduced by a contaminated spacecraft. Based on uncertainties in our knowledge of the diversity of life on Earth, the fact that organisms live in extreme environments on our planet, and indirect evidence that an ocean of liquid water may lie beneath Europa’s surface covering of ice, the SSB [5] and COSPAR [11] recommend a conservative approach toward protecting Europa that assumes the existence of either an ocean or a biota indigenous to the satellite. Given this recommendation, Europa is treated as a special case, and the science goals identified by the SSB’s Committee on Planetary and Lunar Exploration (COMPLEX) reflect the emphasis on the potential for life [12]. The decision to impact the Galileo spacecraft into Jupiter, thereby removing the risk of an inadvertent impact into Europa, was a direct result of the need to practice planetary protection and protect the future science of Europa.

Requirements for Europa flybys, orbiters and landers are structured to reduce the probability of contamination of a European ocean to less than  $1 \times 10^{-4}$ [5]. This standard calls for the explicit calculation of the probability of contamination, and allows spacecraft designers to take advantage of the bioload reduction that occurs from radiation in the jovian environment.

Meeting these conservative requirements will require bioload reduction through the use of clean room technology and the cleaning of all parts before assembly. Spacecraft assembly facilities will require monitoring to understand the bioload and the microbial diversity, and specific bioload reduction methods will be needed to eradicate problematic species. Although Viking-derived cleaning and sterilization procedures would meet the needs of future missions to Europa, more modern processes might overcome some of the technological drawbacks of dry heat.

## 6. CONCLUSIONS

Viking was launched from Cape Canaveral, Florida over 25 years ago. Years before the spacecraft were delivered to the launch site, construction was undertaken to erect facilities needed to assemble and test the hardware before taking it to the launch pad. These facilities included clean rooms to meet the requirements of assembling in a class 100,000 environment, as well as, a facility to enable the Project to meet terminal sterilization requirements. Today these facilities have either been modified to perform other functions in support of the U.S space program, or been left unoccupied over a period of time. One of the twin facilities built to accommodate Viking during assembly and checkout was extensively modified to allow vertical integration of spacecraft like Galileo with an upper stage before being stowed in the payload bay of the Space Shuttle for launch. The terminal sterilization facility built to enable the Project to meet planetary protection requirements, was incorporated into one of the Viking assembly facilities. Years ago the internal working parts of the oven, its gauges and all of the ancillary equipment were dismantled leaving just a shell. This historical and important facility needs to be rebuilt before the U.S. can launch a category IVb or category IVc mission.

In addition to the facilities that the hardware resides in during launch preparations, laboratory facilities for conducting microbiological assays to ascertain the spacecraft bioload during hardware buildup need to be identified and made available on a continuing basis to support missions' planetary protection requirements. These laboratories need to be equipped with state-of-the-art instrumentation to enable the latest microbiological techniques approved by NASA.

Before undertaking a mission to the "special regions" on Mars, even if the mission does not include life detection experiments, the Project must either sterilize the flight system, or sterilize the subsystems that directly contact the special region and then assure the community that there are means to prevent recontamination. Currently, there is no systematic way to model recontamination. Models based on current contamination control particle transfer models need to be developed taking into account both the numbers of microorganisms carried on particles and the plausible transport mechanisms at Mars.

Research efforts to enable the definition of specific requirements and approaches to satisfy them were supported by the Viking Project. Parts were evaluated, selected and controlled in a manner that satisfied sterilization requirements. Today, with new spacecraft materials in use, special screenings are again required to ensure compatibility. These, and other, technical issues need to be addressed as early as possible to support the current NASA strategy and timeline for the exploration of Mars. A properly funded research program would simplify procedures and reduce costs to enable future missions.

Engineering and operational approaches for satisfying planetary protection in the current realm of increased exploration should be developed early in the design process to minimize the impact on the Project. For example, engineering solutions are needed before returning martian samples to Earth to break the "chain-of-contact" with the martian surface, and for containment of the martian sample. Martian material must not be brought back to Earth inadvertently and released without first ascertaining its potential for deleterious effects on our biosphere. Protocols for the safe receiving, handling, testing, distributing, and archiving of materials on Earth are under development [13] and analyses for determining the effects of returned samples are to be determined.

In light of the emphasis on life detection and the technological advances made in life detection instrumentation, processing techniques to clean spaceflight hardware, remove organic contaminants, and sterilize the spacecraft will be rigorously applied to missions to Mars and Europa. Spacecraft material constraints will limit the terminal sterilization cycle, and additional processes to minimize or eliminate sources of bioburden will be introduced by necessity. Projects will need to plan early and define any material incompatibility issues so that materials can be replaced or alternate methods of sterilization and packaging developed. Sterilization and cleaning techniques are only effective if all parts/surfaces are contacted. Viable organisms can be found in the interiors of components and materials and in cracks and crevices. Engineering designs and structures should minimize cracks and crevices whenever possible if these techniques are to achieve their maximum effectiveness.

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