

PLANETARY PROTECTION ISSUES FOR MARS SAMPLE ACQUISITION FLIGHT PROJECTS

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ABSTRACT

The planned NASA sample acquisition flight missions to Mars pose several interesting planetary protection issues. In addition to the usual forward contamination procedures for the adequate protection of Mars for the sake of *future* missions, there are reasons to ensure that the *sample* is not contaminated by terrestrial microbes from the acquisition mission. Recent recommendations by the Space Studies Board (SSB) of the National Research Council (United States), would indicate that the scientific integrity of the sample is a planetary protection concern (SSB, 1997). Also, as a practical matter, a contaminated sample would interfere with the process for its release from quarantine after return for distribution to the interested scientists. These matters are discussed in terms of the first planned acquisition mission.

INTRODUCTION

The objectives of a planetary protection program with regard to a space mission involving the return of a sample from an extraterrestrial body to the Earth are: the absolute protection of the Earth from a possible hazard and the relative protection of the extraterrestrial body from terrestrial contamination. The need for the first form of protection is obvious. The United States National Aeronautics and Space Administration (NASA) Planetary Protection regulations (NASA, 1996) are strict for all extraterrestrial bodies, except those that have been determined by cautious review¹ to pose no threat to the Earth. The exceptions are certified by the NASA Planetary Protection Officer, on a case-by-case basis, to be safe for "unrestricted Earth return." The second type of protection is traditionally concerned with the assurance that later investigations, particularly the search for life, its precursors, and its remnants, by any country's space program will not be damaged by any country's prior missions (e.g., the NASA Planetary Protection policy (NASA, 1995)). This protection, of course, also benefits the later scientific missions of the same country. The NASA Planetary Protection regulations are rigorous for extraterrestrial bodies where the consensus of the scientific community and of COSPAR is that such scientific investigations might have a positive outcome. In the current version of the NASA Planetary Protection regulations, this protection has been extended to the scientific investigations of the *current* mission. Specifically, more stringent requirements

¹ specifically by the Space Studies Board (SSB) of the National Research Council (United States) and by COSPAR

are placed on missions that include “life detection experiments”² than are otherwise applicable to a landed spacecraft.

Forward contamination control for a Mars sample return mission, the subject of this paper, has aspects of both forms of planetary protection. Mars must be protected from terrestrial contamination brought by spaceflight systems that contact it because Mars is an extraterrestrial body of scientific interest in the search for life. Furthermore, the sample to be returned must also be rigorously protected from terrestrial contamination. A more stringent set of requirements assures the scientific value of the returned sample. (This purpose would also be apply to a sample for an *in situ* life detection investigation.) It also ensures that the careful evaluation of the returned sample under quarantine conditions for any biological hazard, necessary because Mars is not considered safe for “unrestricted Earth return,” will not yield false positives. Both of the purposes relating to samples are, of course, unique to sample return missions. This discussion applies equally well to a sample return mission from another body which may be similarly categorized. For the NASA Mars sample return program, the appropriate requirements have been invoked by a ruling by the NASA Planetary Protection Officer that the spaceflight missions to find, acquire, examine, select and store samples to be returned and the spaceflight missions to return the samples are individually and jointly missions with “life detection experiments.”

REQUIREMENTS AND INTERPRETATIONS

Sterility

Based on the recommendations of the SSB (1992) and the ruling that the Mars sample return program is a mission with “life detection experiments,” the lander spacecraft must be sterile, like the Viking Landers³ were after their terminal sterilization. In contrast, the NASA planetary protection requirements for a Mars lander without “life detection experiments” are for limited microbial contamination only (like the Viking Landers prior to their terminal sterilization (SSB, 1992)), a maximum of 300 spores per square meter and 3×10^5 spores on the “exposed” surfaces (e.g., Mars Pathfinder) (NASA, 1996). “Exposed” surfaces comprise the exterior surfaces and those interior surfaces connected by a single unfiltered path to the exterior. Terrestrial microbial contamination could be credibly transported from these surfaces to the surface of Mars. Logically, the sterility requirement for a sample return mission applies only to “exposed” surfaces, those which could permit the contamination of the sampling site or of the sample after it is acquired. As a practical matter, the distinction between the sterility of the Viking Landers, which was accomplished by dry heat sterilization, and a surface sterility requirement depends on the availability of a planetary protection approved surface sterilization modality. As clarified in a later SSB report (1997), whole vehicle heat sterilization was not recommended as a requirement, but merely as an example of a successful protocol.

Alternatively, it would be sufficient to the purpose of protecting the sample from terrestrial microbial contamination if only the surfaces of the sample handling equipment and of instruments which must contact the sample were sterile, provided that these surfaces and the sample itself were *continuously* protected from contamination from non-sterile flight system components until the sample were placed in its own protective container. The sample must also be protected from other system components that were sterile but could become non-sterile during the course of mission operations (i.e., second-hand contamination). This approach would permit major spacecraft systems to be exempt from the “life detection experiment” sterility requirement (but *not* from the usual Mars lander limited microbial contamination requirement),

² as judged by the NASA Planetary Protection Officer

³ Viking '75 Project

with a significant cost savings. Unfortunately, a flight-qualified isolation system is then required, with some monetary and mass costs. However, some breaks in the isolation are necessary to conduct the mission. This factor requires the establishment of an allowable probability of the microbial contamination of the sample and an adequate analysis of the transport of this contamination for the specific hardware design, mission operations and the environments on the Martian surface. The acceptable probability must satisfy the requirement to allow the samples of Mars collected by the sample acquisition mission to be effectively analyzed and certified as safe (for release from quarantine) when returned by a subsequent mission.

Cleanliness

The prevention of organic contamination of the sample is a broader objective that appears to be more difficult than the sterility requirement. Mere sterility permits non-viable microbes, fragments of microbes, organic substances of biological origin (e.g., DNA, RNA, proteins, amino acids, etc.), and other organic compounds that may be mistaken as of biological origin. Although there is no written requirement, the organic contamination of the sample must be avoided to some extent, in view of the modern methods for its detection. These methods and possibly more sensitive ones will be employed both in the planetary protection required evaluation of the returned sample for biological hazard and in the subsequent scientific investigations.

The surface cleanliness “requirement” ranges analogously to the surface sterilization requirement from its most stringent through sufficient alternatives. Fortunately, the release of molecules, but *not* non-viable microbes and fragments of microbes, from an organically unclean surface, may be expected to have run its course during the vacuum exposure of the flight to Mars. On any of the adequate approaches to the sterility requirement, it should be extremely unlikely to contaminate the sample with organic molecules from any component that does not touch it. Therefore organic molecular contamination should be handled by appropriate (low-outgassing) material selection in the design phase for all such components. No organic materials should be used in the construction of any surface that is intended to contact the sample. Here again, a specific requirement (on the allowable amount of organic contamination transferred to the sample) is necessary. However, for the remaining issue, either all “exposed” surfaces of all landed flight systems must be devoid of non-viable microbes and their fragments, or the surfaces of the sample handling equipment and of instruments which must contact the sample must be clean in this sense. In the latter alternative, these critical surfaces and the sample must be protected from all spacecraft systems with unclean surfaces. This approach would permit major spacecraft systems to be exempt from the cleanliness “requirement”, with possible significant cost savings. A flight-qualified isolation system designed to prevent the transport of viable microbes would serve this function as well. As noted previously, some breaks in the isolation are necessary to conduct the mission. This factor requires the establishment of an allowable quantity of non-viable microbial and microbial fragment contamination of the sample. The same transport analysis (as for viable microbes) of this contamination for the specific hardware design, mission operations and the environments on the Martian surface would be employed. The acceptable level must be determined by the needs of the biological hazard evaluation of the sample upon its return. The acceptable level will also set the cleanliness requirement of the sample handling and instrument critical surfaces.

IMPLEMENTATION

The original mission plan for the Mars 2001 mission was that this mission (and Mars 2003) would find, acquire, examine, and cache samples on the surface of Mars for a later return by another mission (e.g., Mars 2005). The equipment and instrumentation for this purpose was to be located on a rover, which would be taken to Mars on a lander. These details are described in the 2001 Lander Mission Proposal

Information Package (MSP, 1997).⁴ Unfortunately, the mission architecture is currently undergoing serious revisions.

Nevertheless, the proposal information package (PIP) provides an outline of an acceptable approach to planetary protection that does not involve complete sterility of all landed hardware. Under this approach, the lander is to be cleaned and processed under the rules for a lander without "life detection experiments." The rover is to be completely surface sterilized (with the option of sealing and isolating the electronics compartment to exempt the contents from all requirements). After cleaning and sterilization, the instrument suite (and the sample cache⁵) on the rover is to be itself isolated. It is understood⁶ that this approach also requires the isolation of the rover from the lander from integration on the ground through deployment on the surface of Mars. This approach can succeed because the rover's biobarrier is opened just before the rover is deployed. The sampling is conducted after the rover leaves the vicinity of the lander *and* after the second biobarrier is deployed.

Another approach considered by the Mars 2001 mission was to avoid the necessity of sterilizing the rover. The elimination of the requirement to sterilize the rover would solve the problem of how to: design an electronics assembly that could withstand dry heat sterilization temperatures, design a system for the aseptic insertion of the electronics after the rover sterilization, or qualify a lower temperature modality. The challenges of this approach are to maintain the sterility of the critical surfaces of the instrument suite and the sample cache during integration with the non-sterile rover and to prevent their recontamination during mission operations (e.g., sampling), when the isolation must be broken. Of particular interest is the protection of the sample in the cache during the lengthy wait for the sample return mission. The execution of this plan requires that the instrument suite and the cache be sterilized already inside their biobarrier. Further, the biobarrier design must permit integration with the rover without any violation of the isolation. Also, the rover would be considerably more contaminated than a sterile rover might become during a deployment from within a biobarrier. Therefore, some type of line of sight shield and a detailed model, supported by simulation data, of the transport of contamination from the rover to the critical surfaces would be required. The PIP approach (acceptable to planetary protection) and the results of its analysis would serve as the benchmark for this and any other proposed plan. Finally a cover would be needed to protect the cache when the sampling operations are complete.

Several technology development issues have been raised by either the NASA planetary protection program suggested approach or by the less stringent approach being considered by the project. With the exception of the contamination transport modeling and simulation activity, to be undertaken by the project itself, tasks addressing these issues have started recently in the appropriate advanced technology program at the Jet Propulsion Laboratory. These tasks include hydrogen peroxide plasma sterilization, modern surface microbiological assay procedures, cleaning processes for biological cleanliness, and deployable flight biobarrier (isolation) systems.

Hydrogen peroxide plasma is a commercially proven sterilization process. Machines for use in hospitals as a replacement for ethylene oxide autoclaves and machines used by manufacturers of medical devices are available. The process reaches modest temperatures, 50 to 55°C, compared to the nominal 125°C (minimum 104°C) for the planetary protection dry heat sterilization specification in NASA (1996). The lower temperature is a great advantage because it is difficult to design electronics to withstand the temperature of the dry heat process. For example, the Viking Project design goal was 125°C, but the

⁴ for the science payload announcement of opportunity, AO: 97-OSS-04

⁵ not stated explicitly in the PIP

⁶ not stated explicitly in the PIP; presumably because it does not pertain to the rover payload.

actual terminal sterilization process only 113°C, a value deemed safe for the hardware. The design effort to accommodate the process was very expensive as well. Modern electronic components and the need to reduce mission costs make this an even greater burden for a Mars sample acquisition return mission. A modest sized machine is currently being used to evaluate hydrogen peroxide plasma for both effectiveness (to obtain Planetary Protection approval) and spacecraft material compatibility. The feasibility of a machine large enough for a rover is not determined.

The work in modern microbiological assay techniques has the objectives of both rapid and complete (including non-culturable⁷) surface sterility verification and non-viable microbe and microbial fragment surface cleanliness verification. The techniques under study include epifluorescence microscopy with fluorescent dye staining and the polymerase chain reaction (PCR). In the microscopy technique, one can tag all microbes for counting with one stain that binds to the cellular membrane and distinguish between viable and non-viable microbes with a second stain that cannot penetrate an intact cellular membrane. The assay is rapid because the three day incubation period for microbial growth into colonies, as in the NASA standard assay (NASA, 1980), is eliminated. The PCR technique is capable of the detection of a few molecules of nucleic acid or parts of a nucleic acid by a replication process that is now commercially available. The work to adapt this process to a planetary protection assay is at an even earlier stage, but cells and fragments are of course detectable.

Little progress has been made in the biological cleaning task. So far no viable candidate process for the spacecraft subsystem or system level has been identified. Some concepts for a deployable flight biobarrier (isolation) system have been considered by the project's design engineers. This work is also in a preliminary stage.

SUMMARY AND CONCLUSIONS

The forward contamination planetary protection task for a Mars sample return mission is formidable. It is apparently exceeded in difficulty only by the back contamination task, where the prevention of a biological hazard to the Earth must be virtually absolute. The forward contamination requirements are somewhat less stringent because the loss of scientific value of the sample or the inability to release the sample from containment in quarantine are not quite as serious issues. The forward contamination task faces several technological challenges: a low temperature sterilization modality for a spacecraft system; non-viable microbial surface cleanliness verification; a biological cleaning method for flight subsystems; and flight biological isolation systems. However, a reasonable start has been accomplished since last year.

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⁷for example, microbes that will not form colonies for counting under the NASA standard assay procedures (NASA, 1980)

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