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Planetary protection: Elements for cost minimization

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Abstract

In line with the UN Outer Space Treaty (article IX of the Outer Space Treaty—London/Washington January 27, 1967) [United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (the "Outer Space Treaty") referenced 610 UNTS 205—resolution 2222(XXI) of December 1966 [1]] and with COSPAR recommendations, for ethical, safety and scientific reasons, exploration of the solar system needs to comply with planetary protection constraints in order to avoid extraterrestrial bodies contamination, particularly biological contamination by terrestrial microorganisms. It is also required to protect Earth from an eventual contamination carried by return systems or samples. The search for life in extraterrestrial samples, in situ or in the frame of sample return missions, must be conducted in order to state with the maximum possible confidence, because the discovery or the non-discovery of life in sample has a direct impact on updations of planetary protection specifications for future missions. This last requirement imposes consequently also for implementation in order to preserve extra terrestrial sample properties, protecting also indirectly exobiological science.

These constraints impose to set up unusual requirements for project teams involved in such solar system exploration missions, requirements based on hardware sterilization, sterile integration, organic cleanliness, microbiological and cleanliness control, the use of high-reliability system in order to avoid crashes, the definition of specific trajectories and their control, recontamination prevention, etc. Implementation of such requirements induces costs, difficult to estimate, but which can be important depending on the solar system target and the mission definition (fly-by, orbiter or lander).

The cost impact of a planetary protection program could be important if some basic rules are not taken into account enough early and consequently, upon past experience, some recommendations can be proposed here in order to manage properly such programs and to minimize their cost.

1. Organization and management

1.1. Outer Space Treaty

Planets, including Earth, and in general all extraterrestrial bodies contamination avoidance are referring to the Outer Space Treaty, particularly to

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the 610 UNTS 205 (January 27, 1967) [1] and to the A/RES/34/68 (December 05, 1979) [2]. These Treaties are handled at United Nation (UN) level and, at least for the first one, have been ratified by practically all nations involved in space exploration.

1.2. COSPAR

Committee of Space Research (COSPAR) has been built by the "International Scientific Council", gathering space agencies and scientific organizations involved in space activities all around the world [8]. COSPAR is observer for the UN and reports regularly after its periodic Scientific Assemblies where planetary program are presented. One of the tasks of the planetary protection session at the Scientific Assembly is also to propose or to update planetary protection recommendations in order to have the approbation of the COSPAR Scientific Council. According to the abovementioned article IX of the Outer Space Treaty, which is very general, the COSPAR planetary protection policy main goal is to give to project teams guidelines in order to avoid the biological contamination of planets, and more generally of all extraterrestrial bodies and of the Earth [3–7]. These recommendations depend on the explored body and the type of mission.

1.3. Space agencies

Using the COSPAR recommendations, the task of the space agencies, through their planetary protection organization, is to write generic and precise specifications for project teams [9], which have to implement them into each concerned project.

2. Requirements

2.1. Extra-terrestrial environment preservation

By analogy with Mars missions, the main requirements [9] are based on the following topics:

- *Orbiter crash probability limitation or sterilization (bioload reduction)—see Fig. 1*: If the crash probability specification is not met, systems intended to fall on the target body must be decontaminated in surface and in depth. Based principally on scientific considerations, this specification imposes to perform trajectory analysis associated with probability assessments, or to perform and verify sterilization processes.
- *Sterilization/biocleaning of lander*: As precedently, the decontamination level must take into account the probability of survival of the most resistant of terrestrial microorganisms in the concerned environment. Sterilization methods must be used with verification of their biological efficiency and lander equipment must be qualified with some margin in order to ensure their survival to the sterilization process. Biocleaning must be easily performed and controlled.
- *Integration in sterile environment*: If the landers are not sterilized in one time after their final integration, they must be integrated into a cleanroom maintained in sterile condition using periodic microbiological monitoring and performing integration facility biocleaning. Operator clothes must be sterile (Fig. 2) and access, including material access, are subject to stringent procedures in order to prevent the cleanroom recontamination.
- *Microbiological control*: Periodical microbiological assessments must be performed on flight hardware in order to verify if the contamination level is within the specification. If not, surface biocleaning must be performed during integration. The traceability of all monitoring must be kept and the final assessments must demonstrate that the specification is met.

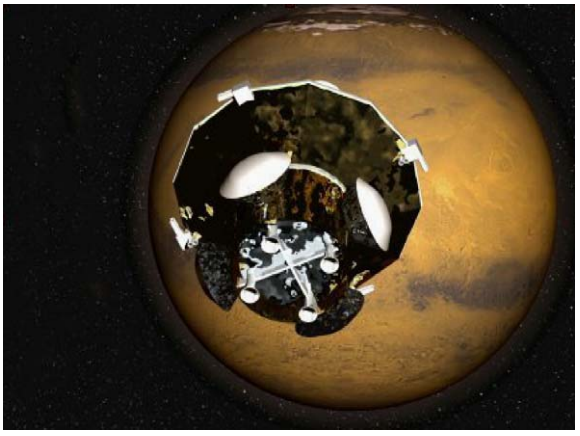

Fig. 1. Mars spacecraft arriving at Mars (photo CNES).

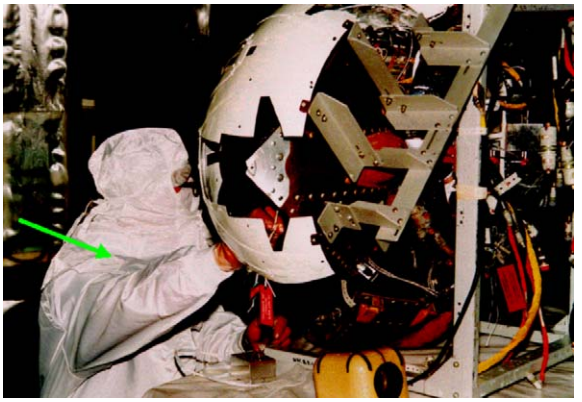

Fig. 2. Mars 96 lander during integration (photo CNES).

- *Bioshield implementation*: In order to prevent any recontamination after the lander integration, the landers must be covered by a bioshield. The internal side of this bioshield must be sterile. This bioshield shall be ejected during the cruise.
- *Organic material list and control*: It could be asked to perform an inventory of all organic materials brought on a planet or smaller body, and eventually to store a part of them, in order to know the organic molecules sent on it.

2.2. Earth environment preservation

Earth environment preservation, in the case of missions returning samples, probes or crews, is a major constraint, because it is directly linked to our biosphere protection and safety. The main specifications should be the following [9], by analogy with the Mars sample return mission specifications:

- The crash on Earth or on the Moon of any return system (including entire spacecraft) shall be avoided. A typically probability of $< 10^{-6}$ may be proposed. This probability impacts directly on the reliability of all systems involved in trajectory injection and maneuvers (motors, attitude control systems, associated electronics, power, etc.). For Mars sample return mission, the specification imposes a probability to release a particle $< 0.2\,\mu m$ (size of nanobacteries) of less than 10^{-6}.
- *Contamination chain breaking*: No free extraterrestrial particle, according to the precedent described specification, must be released into Earth atmosphere, because it could be or contain microorganisms. Extraterrestrial material must be considered as hazardous until proven otherwise. It includes the samples, but also all spacecraft systems or probes returning on Earth.
- *Sample containment*: The samples must be perfectly contained in order to avoid any extraterrestrial particle release into Earth biosphere. It could be pointed out that hermeticity is necessary at least for sample preservation. It is required to control this operation before injection of the return probe into a trajectory meeting Earth, and the only way to control it is to check the hermeticity in flight.
- *Sample analysis in quarantine facility*: The samples must be analyzed in a quarantine facility of class 4 (BSL4—biosafety level 4 laboratory according to US standard, and classe P4—laboratoire de haute sécurité microbiologique—according to french standard), which is the most stringent one (used only for a few applications like Ebola fiever for example). The result of exobiological experimentations is a major issue and no mistake is allowed. During the sample quarantine period of time, experiments and testing protocols must be built in order to state with the higher possible degree of confidence, particularly performing life detection and biohazard testing.
- *Extraterrestrial material sterilization*: Sterilization is not allowed presently, because a sterilization method must be validated and as far no extraterrestrial (and consequently unknown) living microorganism has been found and on which the efficiency of a sterilization process could be validated, it is not possible to be sure to be able to sterilize.

2.3. Sample preservation

If sample preservation is at first a scientific requirement, it is also required in order to ensure the validity of exobiological experimentations, because it is directly linked to planetary protection [9]. If sample preservation is not ensured, inducing contamination or change in sample material properties, some characteristics can be affected and may induce false results concerning presence of life or biohazard. For example, it can change planetary protection policy concerning a target planet and impose inappropriate planetary

protection requirements or decisions (false positive). If no biohazard is detected on samples initially hazardous and in which hazard has disappeared after sample had preservation conditions, it can allow crewed missions on a target planet, able to bring back unexpected contamination on Earth.

Missions having an exobiological interest can be divided into two categories: direct or indirect exobiology. Direct exobiology, which is the search of active forms of life and for which sterilization is required in order to kill any terrestrial microorganisms able to bring confusion in the experimentation results. Indirect exobiology, which is the search of organic compounds linked to past or present life, and for which sterilization is not enough, because the organic matter stay on place with other kind of organic contamination. The problem is that such contamination may be analyzed as extraterrestrial compound and, in order to avoid it, additional efficient cleaning operations may be required.

Protection of samples may impose stringent requirements, and cleanliness is the most important factor and this paragraph will particularly focus on it. Knowing that the samples will be analyzed with efficient and accurate instruments. Their contamination must consequently be absolutely avoided. Cleanliness is a requirement present at every level of a project development, impacting on system design, spacecraft and lander integration process, mission scenario, etc.

The design of landers, or at least systems in contact with samples, must take into account sterilization and cleanability. Materials used for their construction must be chosen avoiding as far as possible the use of organic materials. During integration, the main problem is to maintain the cleanliness and the sterility during the lander integration process. After integration, the landers must be covered with a bioshield, internally clean and sterile, in order to avoid any cross-contamination. During launch and cruise, all equipment which are not protected are subject to contamination coming principally from cross-contamination, for example under the launcher fairing (Fig. 3).

Landing systems are also sources of contamination, because it is generally necessary to fire pyrotechnic devices and depending on the concept, several remarks must be pointed out. Parachutes (Fig. 4) and airbags (Figs. 4 and 5) are built with very large surfaces of organic material and if it is possible to sterilize a parachute system inside its compartment, it is not possible to clean it perfectly and in any case, it releases organic particles.

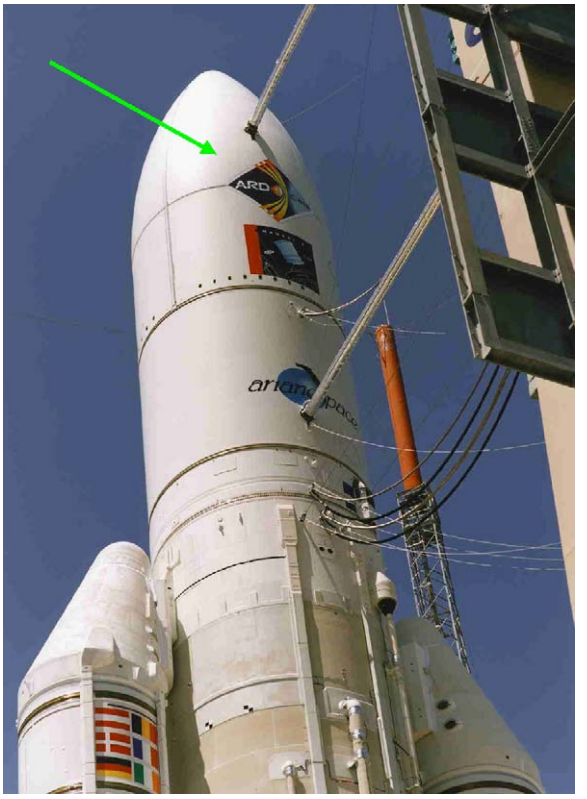

Fig. 3. View of Ariane 5 fairing (photo CNES).

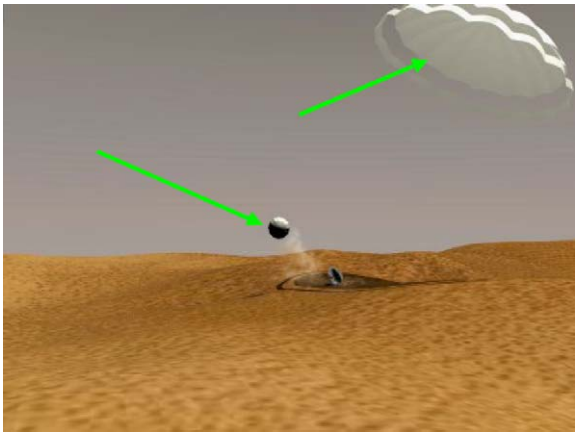

Fig. 4. Mars lander at arrival (photo CNES).

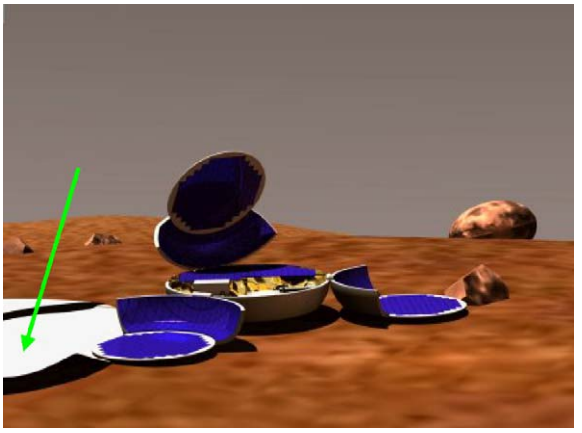

Fig. 5. Mars lander deployed (photo CNES).

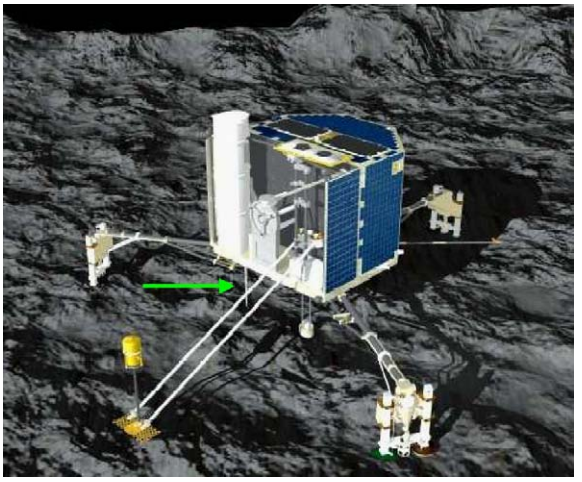

Fig. 6. Rosetta lander in operational phase, during drilling (photo DLR/CNES).

If thrusters are used for landing, the ejectas are a source of contamination and in any case, they can modify the ground properties around the lander. The sample collection system, and more generally all systems in contact with samples (drill, container, etc.) must be built avoiding as far as possible the use of organic material and must be perfectly clean and sterile. The main critical equipment identified at this step are the drill if sub-surface samples are collected, because it is difficult to avoid pollution coming from abrasion phenomenons and lubricant must generally be used, (Fig. 6).

If samples must be hermetically stored, the container closing process (use of gaskets, seal operation, etc.) may also be considered. All instruments used for sample analysis must be free from terrestrial contamination and sterile. Depending on the instrument, it could be appropriate, before any analysis, to measure the "blank noise" inside the instrument before introducing the samples. The goal here is to detect the initial Earth contamination and to identify the contaminants.

3. Elements for cost minimization

The past experiences in planetary protection, for different planetary exploration programs, have induce some reflexion and studies in order to minimize constraints and costs. Advises may be proposed here, and they are the following:

3.1. Harmonization of sterilization methods

One of the first advise could be to try to harmonize the way to sterilize. If one single sterilization method can be used for all systems, it is consequently possible to sterilize the entire probe one single time after integration and closure. It is known that sterilization is cheap, rapid and easy to do. Nevertheless, it imposes to study carefully all lander systems, to specify clearly the chosen method at the very beginning of the project, because all equipment must be compatible with one single sterilization method.

3.2. Use of validated integration procedures

If this condition is not met, a sterile integration is needed with a lot of unusual constraints for operators. It means that after having biocleaned or sterilized all equipment individually with the most appropriate method, they must be unpacked only in sterile environment (cleanroom maintained in sterile condition) and integrated by operators wearing sterile clothes. The external surfaces will be slowly recontaminated, and this fact must be controlled using periodic microbiological assessments (Fig. 7) and biocleaning. To minimize cost during this delicate phase, a set of validated procedure must be required and a training of teams

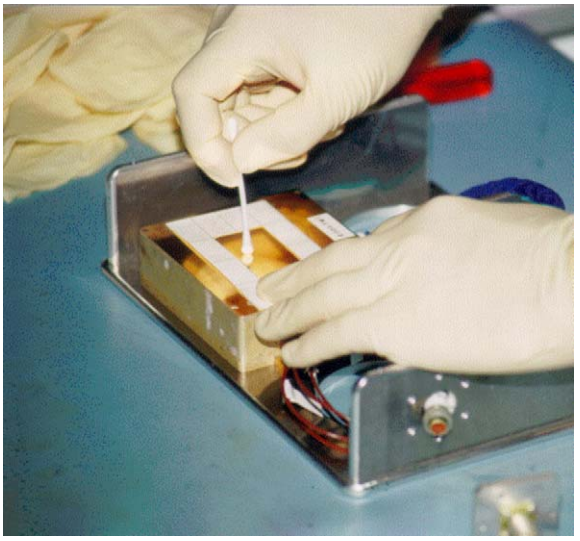

Fig. 7. Microbiological assessment on Mars 96 experiment (photo CNES).

Fig. 8. Mars 96 sterile integration (photo CNES).

is necessary in order to avoid over-recontamination, which has direct impacts on planning and cost (Fig. 8).

3.3. Validation and qualification of sterilization methods

The best solution to find compatibilities between equipment and materials with sterilization methods is to have databases. It avoids to spend time for validation tests at the beginning of a projects and to bring uncertainties concerning the possible compatibility of an entire probe with one single sterilization method. For that, it is necessary to build preliminary research and development programs in order to test and to qualify sterilization methods (Fig. 9). Such program can also cover biocleaning methods and organic contamination control instrumentation. For bacterial spore level determination, the present spore count method needs about 3 days of culture in order to reveal spores and to determine their number per surface unit. The development of a faster method could be more appropriate, avoiding to loose time and avoiding overcontamination difficult to handle.

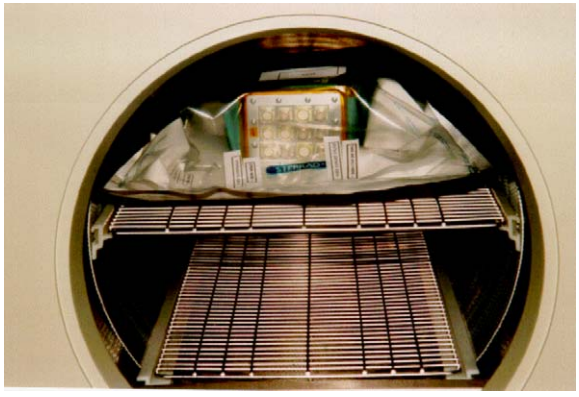

Fig. 9. Mars 96 experiment into sterilizator (photo CNES).

3.4. Early specifications

It is necessary, at space agency level, to have a planetary protection standard [9]. It allows to specify rapidly. It is absolutely necessary to give to project teams requirements very early, because planetary protection constraints is a major constraint to consider, as an environmental constraints, at the same level that mechanical constraints, and thermal vacuum. It impacts on design and material choice and if this advise is not considered, it will be very difficult to find an appropriate sterilization method if its choice is done after design. The risk is to find incompatibilities, needing changes in design and material choice, impacting directly on schedule and cost.

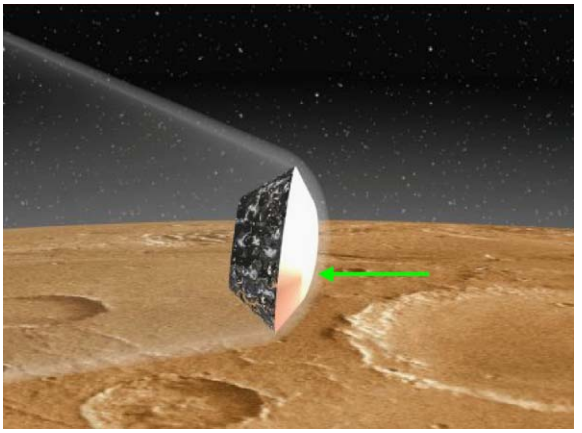

Fig. 10. Mars probe entering into at Mars atmosphere (photo CNES).

3.5. Use of mission events

Specifications in term of microorganism level are given for spacecrafts and landers at the beginning of their operational missions. They are defined knowing the probability of survive in planetary environment (probability of growth and contamination). Presently, the biodecontamination or sterilization activities are used with procedures in order to reduce the bioload to a certain level depending on its probability of surviving in the planetary environment. As far as the sterilization effect of other mission events on bioload remains unknown, specifications remain conservative. It is consequently important to evaluate, with a good confidence, such effect during a mission. Except each planet environment itself, the following events may be taken into account:

- Solar ultraviolet rays exposure (for exposed area). Exposition process to the Sun may be required to comply with it. Bioload reduction function of distance to the Sun is well known.
- Particles (protons, electrons, heavy ions) and electromagnetic radiations (X, gamma) contribution to bioload reduction, is space and particularly in planetary radiation belts.
- Heat during the entry in planetary atmosphere. Reliable thermal models, giving temperature/time exposure, must be used (Fig. 10).

For all events, it is necessary to know the initial surface contamination level. For certain type of missions, such considerations may allow to avoid the use of biological protection before launch if a very good confidence can be given to this calculations. In any case, studies and estimations are needed, but constraints and cost will be much lower.

3.6. Quarantine requirements shall be met for orbiter

It is required to meet such requirements, otherwise the orbiter must be subject to sterilization, at least bioload reduction. No experience exists, and knowing the degree of complexity of spacecrafts, by analogy with small landers, their treatment should be very difficult, added to the fact that the implementation of a bioshield around an orbiter is impossible. Consequently, meeting the quarantine requirement is the best way to work.

3.7. PA program

A strong product assurance (PA) program must be implemented for organic and biological cleanliness control. The goal of it is to prevent overcontamination events, to handle problems and non-conformancies, and to define corrective measures in order to avoid further contamination problems.

3.8. Early evaluation of the program cost

It must be considered that a few percent of a program cost is the consequence of planetary protection requirements. The cost does not come only from biological and organic cleanliness (direct cost), but also from indirect costs like, for example, system reliability or trajectories needing additional resources. For sample return missions, the back-contamination constraints must be carefully considered in terms of cost, because such a program needs a quarantine facility for samples, engineering for systems breaking contact chain, high-reliability systems in order to avoid crash on Earth, cross-contamination control systems, etc., and taking into account Earth contamination classified presently as catastrophic, no waivers at this level can be allowed. No program shall be decided without having carefully estimated such non-negligible cost. The

risk here is to decide a program, discovering later that it is too expensive, leading to its cancellation.

4. Conclusion

Space agencies and project teams involved in space exploration programs are concerned by planetary protection, for ethical, legal and scientific reasons. Planetary protection implementations need clear specifications in order to comply with Earth and extraterrestrial bodies preservation, jointly with scientific goals. Planetary protection requirements are present at every level of a solar system exploration project, and have to be taken into account early. The impact of planetary protection implementation in a program has costs which, for mainly of them, cannot be neglected. Efforts to minimize them without waiving on specifications are welcome, increasing the chance for such planetary exploration program to be decided by Space Agencies Program Directories.

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