Planetary Protection 19

Since the dawn of the space age, contamination, biological or otherwise, carried from Earth to outer space and brought back to Earth from outer space has been an issue of concern. Contamination of other celestial objects originating from Earth is called *forward contamination*, while that from other objects upon Earth is called *back contamination*.

With the launch of Sputnik 1 in 1957 the International Council of Scientific Unions, now the International Council for Science, established in 1958 its Committee on Space Research (COSPAR). The purpose of COSPAR was, and continues to be, to promote an international level for scientific research in space, with emphasis on the exchange of results, information, and opinions; and to provide a forum for the discussion of problems that may affect scientific space research. In its first years, COSPAR played a significant role as a bridge between East and West regarding cooperation in space. The most significant outcome of its efforts was the establishment in 1967 of The International Space Treaty, which, apart from creating a basis for international fairness and parity regarding space science and exploration, developed the first Planetary Protection policy to which all space-faring parties signed up, stating in part that "Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter, and where necessary, shall adopt appropriate measures for this purpose."

At the time, the only human missions into space were into low Earth orbit, except of course the first landings on the Moon between 1969 and 1972. Although COSPAR-based back contamination countermeasures were generally followed, it was quickly realized that the surface of the Moon did not pose a toxic or biological contamination treat. Furthermore, with no human missions beyond low Earth orbit in the intervening decades, the lion's share of concerns about contamination have concentrated on forward contamination of the other worlds of the Solar System visited by our many

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robotic explorers. Indeed our approach here has been quite specific, requiring stringent limitations on forward contamination of all celestial objects, but especially those providing insight into questions of origins and of the possibility of life elsewhere, to ensure that scientific exploration or the advancement of knowledge is not impeded. Although this approach seems (and is to an extent) laudable, it is worth noting that the emphasis has been on safeguarding our ability to conduct scientific research, not on safeguarding the purity of any prospective environment we visit. The requirement is for contamination (microbial or otherwise) carried from Earth on board our spacecraft to remain below the detection limits of our instruments when looking for clues for life-related activity on other worlds; but there is no absolute requirement for the protection of potential indigenous life on those worlds. It has been realized, none the less, that it would be impossible to completely sterilize our space hardware; and while we may not specifically cite the protection of potential microbial life on other worlds of the Solar System, the COSPAR treaty and resulting recommended countermeasures are stringent.

Overall, there are five categories to consider with regard to contamination. Category 1 deals with objects such as our Sun and the planet Mercury, of which no containment countermeasures are required. Category 2 considers missions whose trajectory approaches no celestial objects and again no particular countermeasures are needed. Category 3 includes fly-by craft and orbiters to targets of biological interest and where a risk of contamination therefore exists. Countermeasure procedures here include a requirement of the biological-burden (microbial life likely to reside on the visiting craft) to be determined, documented, and declared, as well as some clean assembly and trajectory measures to minimize the risk. This is the first category relevant to the exploration of Mars. Category 4 deals with lander missions to targets of chemical evolution and/or origin of life interest. In the special case of Mars, this category has been divided into three subcategories, with anticontamination measures compared against the Viking landers; such was the stringency of countermeasures applied during their assembly:

- Category 4(a): Missions to sites not carrying instruments to search for extant life must carry a biological burden not greater than the Viking lander presterilization levels (i.e. the probe is clean but not sterilized).
- Category 4(b): Landers looking for extant life must be clean-assembled and completely sterilized to at least the post-sterilization levels of biological-burden of Viking—or higher if the investigation requires it.
- Category 4(c): Lander missions to special regions require post-sterilization to Viking lander missions for all aspects of the landing

assembly—the descent capsules, parachutes, airbags, etc.—and not just the probe carrying out the scientific investigation.

Finally, Category 5 deals with all Earth return missions, which are called *restricted Earth return missions*. Here the outbound part of the hardware must comply with Category 4(b) regulations to avoid *false-positive* identification of life and for any acquired sample to remain completely sealed. Furthermore, the sequencing of mission vehicles must break the chain of contact between those in contact with the target and those returning to Earth, while the mission must be continuously monitored, with immediate analysis upon return to Earth to determine the potential biohazard.

Redeveloping Planetary Protection Policy

Forward Contamination

Over the decades, COSPAR guidelines, ESA's and NASA's own internal procedures, and recommendations from such organizations as the Space Science Board (part of the US Nations Research Council) have all provided for a generally robust and widely accepted level of measures to ensure minimal forward and back contamination. But there have been, as we have seen throughout this book, significant recent developments in our understanding of the robustness and diversity of microbial life, our understanding of Mars, and the imminent prospect of deep-space human missions there, for example, that all prompt serious re-examination on how planetary protection is perceived, managed, and pursued.

With recently renewed recognition of a possibility of past and present life on Mars, issues of both forward and back contamination take on a new relevance. It is our hope—based on scientific grounds—to find evidence of prebiotic chemistry, extinct, and even extant life on Mars, and in this light issues of contamination need to be pursued in a more sophisticated manner. For example, given our new awareness of the diversity of microbial life on Earth and the sophistication of current instruments, we now realize that Viking post-sterilization levels of contamination likely to be on board a Mars lander are not sufficient to guarantee that a false-positive result will not arise. So sensitive are our instruments, so tentative may be the evidence, and so adaptable may be Earthly microbes, even on Mars, that upcoming missions will require greatly enhanced clean-assembly, sterilization, and auditing of the bioburden upon our exobiological landers. Here we will have to research the nature, survival, and growth of bioburdens upon spacecraft in conditions matching interplanetary space, as well as the surface of Mars, from which new and sophisticated techniques of assembly and sterilization must be developed.

Ethical issues also arise with the prospect of detecting life-related activity on Mars. For example, should a positive identification of life be made on Mars by robots, the question of whether to send people there would take on a new significance. Currently, there is no clear policy on such an eventuality, although it is unlikely that people would be sent to Mars until any detected life was well characterized and the potential biohazards determined and managed. Indeed, both Aurora and VSE aim to determine the existence of life on Mars and will only subsequently make a decision to send people there. Even so, sufficient countermeasures are not yet in place and must be developed before any human mission can take place.

Also, it is currently unclear how we value alien life. Indeed no legal framework and/or code of behavior yet exists regarding the protection of Martian microbial life, should it be found. This may at first seem unimportant, but should such a discovery be made it will become immensely critical not only with regard to treatment of the life itself but also regarding any international agreement on how to deal with the discovery. There are two broad approaches to the ethical dimension to Martian life. One school of thought proposes that Mars should then be left alone and that, however basic or sparse, any existing Martian ecosystem has a right to exist, develop, and evolve of its own accord. Furthermore, where benefits can derive from studying Martian life—such as understanding our origins, the nature of life there, and a general context for all biology with the potential medical and technological spin-offs—our interests will best be served by pursuing our investigations with the utmost care and by ensuring that there is no fundamental impact upon the Martian biosphere. A second school of though argues that, being part of nature and the evolutionary process, all actions by us, however invasive upon Martian life, are also part of nature and are therefore beyond ethical questioning. Hence, a course of action that provided maximum benefit to humans is reasonable.

However we pursue Mars, even our purest intentions will be, and have already been, invasive. As discussed above, our science interests to date have only acted to safeguard the Earth, not prospective Martian life, and it is already certain that the space probes that have landed on Mars have carried microbial life from Earth that may survive in the long term. And although the rate at which we are exploring Mars may seem low, there is no telling how we might impact upon the planet over a prolonged period, despite current countermeasures. We are already placing Mars in a long-term position that is unclear regarding the survival and spread of earthly microbial life there, irrespective of the existence of indigenous life. When we consider the full gauntlet of potential interest in Mars—human missions and outposts and resource utilization in the coming decades—ethical issues may not be considered. If our record on Earth is a benchmark, then unless there is a significant change in how we value life and the natural environment, Mars will fair no better.

But here there is an opportunity. If so much of what is done badly with Earth's environment is simply bad habits, poor planning, and historical legacy, then we can, by default, explore and pursue Mars in an improved manner from the outset, better safeguarding its environment while also protecting our long-term interests. Indeed, when we consider the possible benefits even for the medium term, such a strategy is not only wise, but probably necessary. With those benefits mostly being of a scientific and sociological *information* nature, and with potential biological and medical benefits (should evidence of even sparse life be found), it is surely incumbent upon all concerned, irrespective of ethical stance, to vastly improve how we deal with forward contamination on Mars. Indeed, the scientific community can take the lead in this respect. Even if society at large cannot agree on an ethical stance, or if economic and political forces eventually come to the fore, the head start that the scientific community now enjoys can provide an opportunity for a statement to be made—and for the foundations to be laid—regarding the best way to pursue Mars for the maximum benefit of the Martian environment and for our hopes and aspirations.

Back Contamination

With the prospect of a Mars sample return mission within a decade, and human missions within three decades, the policy surrounding back contamination also needs to be redeveloped to a far greater degree. Two issues arise in this area: (1) the biohazard risk associated with robotic sample return to Earth, whether or not we know it to contain life; and (2) the risk to humans who travel to Mars and the associated risk to Earth upon their return. In both cases, it is incumbent upon the space science community to recognize the scale of these risks and to take appropriate action, irrespective of the short-term impact upon the quality of the science. As with other areas of earthly environmental science, the risk is not simply a function of the likelihood of microbial life within a given sample, but a product of that likelihood and the worst case scenario's impact upon Earth's environment. While the likelihood of life on Mars and in any returned samples is extremely low, a worst case scenario—where, for example, microbial life was accidentally released into Earth's biosphere and impacted catastrophically on human life or agricultural yields—constitutes a truly unacceptable risk with potentially horrendous consequences. In the absence of valid testing or of any meaningful information, our communal responsibility demands that we regard the risk as extremely high, and for extreme back contamination measures to be implemented. In any case, national and international governing bodies, environmental protection agencies, agricultural boards, and the general public would all find it utterly unacceptable to allow any potential biohazard anywhere near the planet without extraordinary countermeasures put in place.

Mars Sample Return

Any sample return mission from Mars will represent a significant biohazard; and while COSPAR's Category 5 containment recommendations are sufficient, their implemention represents a significant challenge (but is now being hotly pursued by COSPAR and the major space agencies of the world).

While we can develop a mission strategy that can break the chain of contact near Mars, it is in the secure handling of the samples *en route* back to Earth, their safe arrival on Earth, and their subsequent secure handling for scientific analysis across many locations on Earth that pose the major challenges. We will have to develop proven failsafe containment systems that completely guarantee safe delivery of samples from Mars to contained environments on Earth for subsequent analysis. Other measures will also be required, such as combustion or sterilization of the samples before their arrival back on Earth. Currently, several groups are working to develop verifiable containment systems, to be ready before our first sample return mission some time in the next decade.

People Visiting Mars

Protecting people who visit Mars, and subsequently protecting Earth from their return, will present an enormous challenge. As with current robotic exploration, where forward contamination cannot be fully prevented, absolute guarantees of protection of people who land on Mars will never be possible. The decision to send people there will therefore constitute a risk, where the best we can hope to achieve is to minimize that risk through initial surveys of the planet as a whole, the surface environment, the atmosphere, and finally any chosen site, followed by appropriately designed anti-contamination measures. If life is detected prior to sending people to Mars, however, a far-reaching analysis of that life will need to be made to access its potential threat, perhaps delaying a human mission by years, if not decades, until the threat is fully appraised and can be adequately dealt with. However, if we detect only the presence of past, fossilized life or no life at all, we will ultimately have to make a judgment based on incomplete information as to the potential biohazard to the crew. Similar to the situation regarding forward contamination of Mars by robots, we will probably reach a point where, even with incomplete information, we will deem the risk worth taking for the sake of exploration and scientific advancement. We will in any case be able to take many precautions. We are rapidly becoming technologically and logistically sophisticated enough to reduce any threat to potentially molecular levels, meaning that we can detect even molecular level threats and can safeguard against them. Even where contamination was to occur, despite the ethical dilemmas arising, the lengthy nature of the stay on Mars would probably provide sufficient time to gain insight into the nature of the contamination and threat to people and other terrestrial biology. Furthermore, any remaining uncertainty regarding the nature of the threat could then be dealt with within the vicinity of Earth, where the crew and/or other materials to be accessed could be performed on lunar bases, in Earth orbit, or within adequately contained environments on Earth.

Future Actions

It is now clear that many of the issues of forward and back contamination, and planetary protection in general, remain unresolved and need urgent action. The existing laws, legislation, policies, and procedures are inadequate to deal with our aspirations of sample return and human missions to Mars. Indeed these and the many ethical issues regarding our view of, and approach to, Mars also require urgent widespread and public debate, and here there may be a role for such outreach organizations as The Planetary Society as well as the leading astronomical organizations of the world.

In deference to the outstanding issues however, all the leading space agencies, science organizations, and even the United Nations (through COSPAR) are now frantically engaging the issues. NASA, for example, recently requested the US Space Science Board to conduct a review of planetary protection policy, followed by recommendations. ESA is also actively engaging a number of workshops on how best to proceed from here. Issues to be addressed include greatly reducing forward contamination on Mars, developing verifiable failsafe containment systems for a sample return mission, as well as initiating a far-reaching debate regarding the ethical issues surrounding life on Mars and back contamination. Subsequently, national and international treaties, policies, and laws will have to be updated if our newly developed procedures and methodologies at safeguarding both Earth and Mars are to be effective in this time of increased interconnection between both worlds.

Following NASA's request, the Space Science Board conducted an extensive review, publishing their findings in August 2005, with the following recommendations:

- For the development of superior sterilization techniques—to the molecular level—and reflecting our increased understanding of the robustness and diversity of microbial life on Earth. These include steam, gamma radiation, and hydrogen peroxide plasma sterilizing technologies.
- For formal recognition of the increased importance of Mars, including making all of Mars a *special region*.
- For the development of verifiable containment systems for a sample return mission.
- For research to be conducted into the nature of the biological burdens that are carried to Mars on board our space probes and for research into how those particular microorganisms behave in Martian environments.
- For a wide debate, involving the public, regarding the ethical issues of alien life in general, regarding making all of Mars a special region and regarding back contamination.
- For NASA to fund research into new sterilizing technologies and the development of failsafe containment systems.
- For NASA to hold workshops with COSPAR, ESA, among others regarding all planetary protection issues.

The Space Science Board also recognized an urgency to these issues, given our rapidly changing and improving understanding of Mars and our already operating long-term robotic program, imminent sample return, and possible human missions. To this end it also recommended some interim steps that need to be taken immediately if a sample return mission in particular is to take place within the next decade:

- For current planetary protection policy to be updated to reflect recent findings regarding microbial life on Earth and about the nature of Mars.
- In particular, for major efforts to distinguish special regions, or to consider all of Mars a special region.

- Special measures to be implemented to protect already known special regions.
- NASA to initiate an adequately funded transition to more resilient planetary protection measures.
- NASA to immediately initiate new workshops and research into a long-term planetary protection policy to match its ambitions on Mars.

Furthermore, the following time line was proposed by the Space Science Board:

- A new planetary protection road map to be immediately developed.
- Testing of new sterilization techniques to be completed by 2008.
- Analysis of space probe biological burden, and its likely impact on Mars to be determined by 2012.
- Fail safe containment systems to be developed prior to a sample return mission.
- All interim policies and systems to be in place by 2016.

Combined with the practical necessity to protect Earth as best as possible, we have much to think about and decide upon regarding how we value life on Mars, and indeed all life. These issues force our hand to examine life in a broader context, to think of ourselves in a broader context, and to think about our long-term wellbeing. The decisions we come to will in part define who we are. In this light we have an unique opportunity to take a valued stance on an issue new to our time, but it is also one on which we will be judged by future generations. A direct ethical connection has been established between our humanity and the possible microbial make-up of Martian soil.