Session 3

Environmental Concerns

DISCUSSION PAPER:

"Environmentally Sustainable" Space Exploration: Reconciling Challenges Of Planetary Protection

by

Molly K. Macauley[1]

…. Scientists have pressed, as early as the dawn of the space age, for measures to protect celestial bodies from contamination by Earth organisms that could hitchhike on a spacecraft, survive the trip, and grow and multiply on the target world – Joshua Lederberg, 1957 letter to the National Academy of Sciences, reproduced in Space Studies Board, 2005.

… Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own need – The World Commission on Environment and Development (The Brundtland Commission), Our Common Future, 1987.

1. Introduction

Protecting planets from the introduction of nonnative organisms has long been a concern in space exploration. Separately but at the same time, public understanding of and willingness to protect the earth environment, while pursuing economic growth, has grown significantly in both industrialized and developing countries. Some discussion involved in development of planetary protection guidelines has borrowed from or referenced this public compassion for environmental protection and asked to what extent it carries over to celestial environments. Are space explorers to be stewards of other planetary environments? McKay (1990), Lupisella (1997), and others have asked, "Do Martians have rights?" Is a new way of thinking – Haynes (1990) coined the term cosmocentrism – necessary to expand geocentric environmental concepts? Is understanding of other planetary environments sufficiently informed to provide a basis for knowing what to protect? And, even if the answer to these questions

[1] Senior Fellow, Resources for the Future, Washington, DC. The author has benefited significantly from extensive discussions with Linda Billings, who also very generously shared many of her detailed files of references. I also appreciate the insights so readily shared by Bill Gail. Neither of these scholars has reviewed this paper, however, and the author remains fully responsible for errors and opinions. The support of Resources for the Future is gratefully acknowledged, as is the opportunity provided by Professor Ram Jakhu and the sponsors of this conference.

is "yes," does planetary protection conflict irreconcilably with exploration?[2]

This paper argues that ultimately, achieving balance in efforts to protect planets and other bodies will depend irrefutably on the goals of space exploration. To take an extreme example discussed later in the paper, suppose the goal of exploration is to colonize other planets for the purpose of ensuring perpetuation of the human species in the event of a widespread terrestrial pandemic. In this case, safeguarding other planets to protect the scientific integrity of our search for life there – at present, the rationale for most planetary protection activities -- will probably weigh very little in the public mind. Instead, in such an extreme situation, a push to colonize could become quite popular, paced by the expected temporal proximity of the catastrophe with little regard for much else.

The other extreme is to conduct no exploration activities at all in order to maintain planets in their pristine state.[3] A recent report by experts engaged in Mars exploration points out (but does not endorse) that "the only way to fully eliminate risk is to stop direct contact missions, and go to passive observation"[4] (although even then, the chance remains of an accidental crash of passive observing systems). Shy of these two extreme cases, one arguing against any protection and the other against any exploration, the rationales for planetary protection and for space exploration become tightly coupled. (This outcome is just like the decision to live with some amount of dirty air or dirty water because the alternative is to virtually shut down all human activity.) The willingness to forego some amount of protection – that is, to accept the effects of exploration on other planetary environments – becomes the agreed policy. The devil then is in the details of determining the right amount, nature, and timing of protection. It is in achieving this balance that clarifying the "why" of space exploration becomes essential.

Section 2 of the paper gives background information on planetary protection and

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[2] This paper deals with government exploration, not privately funded and operated activities.

[3] Natural contamination (such as micrometeorites exchanged between Mars and earth) and past man-made contamination (such as intentional and accidental landings on Mars by robotic mission) and their confounding effects on the search for life are the subject of occasional discussion in the scientific literature. Three Soviet spacecraft and four NASA spacecraft have landed or crashed on Mars. The desirability of environmental remediation – "clean up" -- of potential contamination on Mars from these previous missions is also among concerns. The Space Studies Board, 2005, p. 18 notes but does not agree that "An extreme viewpoint would be that, since some past missions have already likely delivered significant quantities of microorganisms to Mars, and since Mars experiences substantial windblown transport of dust, there is no longer any point in continuing planetary protection practices." The report dismisses this conclusion because the probabilities of forward contamination involving microorganism survival and growth are inherently small. However, the report urges taking care to keep the sum of these probabilities small over future missions.

[4] See Beaty and coauthors, 2006.

current approaches. Section 3 turns to the main theme, the challenge to protection in a new era of human space exploration. Sections 4 and 5 discuss rationales for planetary protection and maintain the criticality of clarifying the goals of human exploration. Section 6 advances the idea of "sustainable human space exploration" in the spirit of the Brundtland Commission (see quote, above). Section 7 offers conclusions.

2. Background

This section summarizes a large and growing literature on planetary protection and relies heavily, although not exclusively, on studies conducted by the National Research Council's Space Studies Board at the request of the US National Aeronautics and Space Administration (NASA).

2.1 What is planetary protection? Planetary protection seeks to safeguard earth as well as other planets and celestial bodies from the potential contamination created during exploration of space. Contamination can occur in many ways. For example, it may take place when spacecraft introduce microorganisms, or bioburden, by way of landing or accidentally crashing on a planet as well as during research operations (roving, mapping, sampling) carried out on the planet. Protective measures also seek to safeguard Earth from contamination when space missions return to earth.

The desire to safeguard celestial bodies from Earth life introduced when spacecraft land on or otherwise contact these bodies – the outbound leg of the trip – has come to be known as forward contamination. Protecting Earth from organisms collected from extra-terrestrial bodies – the return leg of the trip -- is known as backward contamination. A concern involving both outbound and inbound trips when the mission is returning samples (say, of rocks, soil, dust, or other materials) surrounds preserving the integrity of samples themselves by collecting and handling them in a manner to protect them from contamination by terrestrial organisms. Such contamination would confound scientific analyses – for example, by possibly leading to a "false positive" conclusion as to the presence of living organisms.

The kinds of safeguards that can be taken include a range of engineering and mission-planning steps. For example, to mitigate forward contamination, spacecraft can be assembled in clean rooms and decontaminated using heat or other sterilization procedures. Other measures can guard against microbial release such as using shrouds, filters, and seals. Missions and hardware can be designed with extra redundancy to reduce the chance of accidental crash ("non-nominal impact avoidance," in the jargon). Inventories can be made to document information about the kinds and amounts of bioburden which are associated with the activity to provide a background record. In the case of backward contamination, the returning spacecraft, astronauts, and samples can be quarantined at an intermediate orbiting space station or on earth. Samples can be sterilized, although how best to do this without destroying their scientific properties has always been an issue. For instance, it is desirable to store samples from Mars at low (subfreezing) temperatures and in an atmosphere of gas composition and pressure that reproduces the Martian environment. Designing a facility with these characteristics, as well as the operational procedures to handle and study the samples, could be complex.

2.2 Current standards for protection measures. These safeguards are more formally specified and standards are set for many of them in international and national policies. The Committee on Space Research (COSPAR), under the International Council of Scientific Unions (ICSU, now the International Council for Science) is the international policy-making organization on planetary protection (and is a consultative body to the United Nation's Committee on the Peaceful Uses of Outer Space). In 1969, COSPAR promulgated the first formal standards. They specified an overall, cumulative limit for the next 20 years determined by a set of factors: the bioburden at launch and the probabilities of bioburden surviving the journey, an impact with the planet, and release and growth of the microorganisms. This overall limit was allocated among spacefaring countries. The countries in turn allocated a limit over their space missions within the 20-year period.[5]

Based largely on concerns that these probabilities included a number of "guesses" and that the 20-year period may be too short to represent the accumulation of contamination, COSPAR has since changed the standards to use more performance-oriented rather than exclusively quantitative measures. Space missions must now meet requirements depending on the type of mission and the destination. A mission can fall into one or more of several categories determined by whether it will make direct contact with a body and whether it will return to Earth. Depending on the category, a mission may need simply to provide certain documentation (for example, if flying by a comet and not returning to earth) or meet much more rigorous steps involving sterilization and additional prevention measures. In 1992, COSPAR added additional categories for Mars exploration with more stringent protection required for missions that would be searching for life on that planet.

In 2002, COSPAR added another category for Mars exploration, designating "special regions." A special region is "a region within which terrestrial organisms are likely to propagate, or a region which is interpreted to have a high

[5] Good discussion of these measures is in meeting notes of NASA's Planetary Protection Advisory Committee, June 10 –11, 2004, p. 11.

potential for the existence of extant Martian life forms." These special regions are based on current understanding of where liquid water is present or may occur, including subsurface depths, the polar caps, and areas of hydrothermal activity. If making contact in these regions, spacecraft have additional bioburden restrictions and sterilization requirements.[6]

These provisions for special regions, along with the rest of the COSPAR categories, are incorporated into NASA's procedural requirements for planetary protection. NASA maintains a planetary protection office and since 2001, a Planetary Protection Advisory Committee (PPAC), part of the NASA Advisory Council.[7] The Planetary Protection Officer at NASA is responsible for overseeing space missions to ensure their implementation of relevant protection measures. The PPAC is required to include representatives of the public, private, and academic sectors with some members having expertise in fields of bioethics, law, public attitudes and the communication of science, the Earth's environment, or related fields. Nonvoting members represent the Departments of Agriculture, Energy, Health and Human Services (National Institutes of Health and Centers for Disease Control and Prevention), Interior, Transportation, and the US EPA, NSF, and White House. The Committee may also invite the participation of nonvoting liaison representatives from other national and international organizations undertaking joint solar system exploration missions with NASA.[8]

In a new set of recommendations for protecting scientific integrity of robotic exploration of Mars, a committee of the Space Studies Board found that all of Mars might be considered a special region because there is inadequate information with which to distinguish such regions.[9] A recent report by NASA's Mars Exploration Program Assessment Group (MEPAG), in response to the issue of special regions, takes exception with the finding.[10] The MEPAG report summarizes a host of detailed research results about the Martian environment and concludes that these results permit greater specificity about regions where either terrestrial organisms could reproduce or where there is high potential for extant Martian life. MEPAG proposes guidelines that differentiate non-special and uncertain regions and another category, induced regions, such as where spacecraft contact or operation may create a special or uncertain region.[11]

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[6] COSPAR Planetary Protection Policy 20 October 2002 and Appendix Revisions 24 March 2005 at http://www.cosparhq.org/scistr/PPPPolicy.htm (accessed June 2006). Discussion of the new designations is in Space Studies Board, 2005.

[7] See http://planetaryprotection.nasa.gov/pp/index.htm (accessed Mar 27, 2005).

[8] See National Aeronautics and Space Administration Charter of the Planetary Protection Advisory Committee of the NASA Advisory Council at <http://science.hq.nasa.gov/strategy/ppac/PPACCharter.html> (accessed November 2005).

[9] Space Studies Board, 2005.

[10] Beaty and coauthors, 2006.

[11] One of the most cited examples is that a radioisotope thermal generator on a spacecraft may act as a perennial heat source that could encourage propagation of terrestrial organisms.

3. New momentum for concern about planetary protection

Recent additional developments have heightened the immediacy, and complexity, of protection efforts.

3.1 New information. One development is new knowledge about the possibility of past or extant life on Mars.[12] A related finding is discovery of the diversity and survivability of terrestrial microorganisms in extreme environments, a source of forward contamination (when these microorganisms survive the trip into space) but also a finding related to whether organisms on other planets are more adapted to planetary environmental extremes than previously thought.[13] A separate but growing concern is the high failure rate of Mars landers in the past – each time, possibility adding contamination to the planet – coupled with the projected rapid pace of future spacecraft investigations on Mars planned for the coming decades.

3.2 Plans for renewing and extending human exploration. There is an additional incentive for heightened attention. The US Presidential announcement in January 2004 of the goal to send humans to the moon, Mars, and beyond necessitates review of existing protection policy for at least three reasons. One reason is the desirability of expediting understanding of potential risks to humans from the alien planetary environment. Policy initially developed during the Apollo program sought to protect astronauts from harm (and quarantine them upon their return to protect Earth from any contamination they may have brought back). A 2005 study by the National Research Council, *Safe on Mars*, has identified some of the critical human safety issues for human exploration of Mars.

The push for human exploration, and the pre-cursor robotic sample return missions to prepare for human travel, also add a sense of urgency to reevaluate existing protocols to ensure their adequacy to protect earth from any potentially harmful contamination on the return trips. Ongoing research, review and expansion of existing protocols seek to address this concern (and the infrastructure development for a "containment facility" to house samples needs both expedited planning and adequate funding).

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[12] Beaty and coauthors, 2006, and Space Studies Board, 2005.

[13] Recent studies report detecting organisms able to withstand extreme conditions (temperature, salinity, radiation, drought), such as the discovery of organisms living in deep-ocean thermal vents. Organisms such as these, known as extremophiles, are among those thought to have the best chance of surviving and replicating in Martian environments and are a potential source of forward contamination on Mars. Extremophiles could also be a potential source of back contamination (Meeting Notes, PPAC, 8-9 February 2005, p. 8). Previously understanding of life detection had been largely limited to the presence of heat-resistant, spore-forming bacteria which could form on spacecraft and be a potential contaminant (Space Studies Board, 2005).

A third implication, and the focus of the rest of this paper, is the additional forward contamination that will be introduced by human explorers. As a colleague has put it, "With human exploration, we're sending to Mars the very biological agents we take great care to eliminate from the robotic spacecraft we send."[14] Because of new evidence of the potential for past or extant life on Mars, and the desire to avoid false positives in further search, a significant and immediate challenge for planetary protection is whether and if so, to what extent, to restrict human exploration. Or, to put it differently, will the goals of planetary protection need to be compromised to accommodate human explorers? Yet another possibility is whether pursuing both human exploration and planetary protection can be mutually supportive rather than at odds.

Human planetary exploration introduces new concerns about safeguarding planetary environments. Humans add to bioburden by way of the additional spacecraft, rovers, telecommunications, life-support, and other infrastructure that a journey requires. An accident in which the integrity of spacesuits or other protective gear were to be breached is another source of contamination. Humans involved in long-duration stays may also require that the planetary environment be transformed to make it habitable.[15] The Space Studies Board has pointed out that:[16]

> Human missions will inevitably introduce considerations that go beyond those covered by the forward contamination controls and policies discussed in {the Committee's} report, and are likely to include examination of COSPAR policies and questions about minimizing potential contamination that could be introduced through human operations, exploration, construction, sampling, and sequencing of activities. At present, there are no official COSPAR or NASA policies encompassing forward contamination of solar system bodies during human missions.

[14] Special thanks to Bill Gail, who penned this in email correspondence in June 2006.

[15] More aggressive alteration of planetary landscapes includes genetic engineering to transform planetary resources and organisms, or planetary engineering to "terraform." Examples of terraforming to make Mars more habitable for humans include vaporizing the Martian polar caps or mixing dust or sand into the ice to reduce its reflectivity for the purpose of raising the temperature on Mars (see Sagan, 1973; Averner and MacElroy, 1976; McKay, 1982); vaporizing carbonate rocks on Mars to free carbon dioxide and possibly melt enough permafrost to create bodies of water (Fogg, 1989, 1992); releasing greenhouse gases to warm Mars (McKay, Toon, and Kasting, 1991; Marinova, McKay, and Hashimoto, 2000); using a space-based mirror to boost sunlight and warm Mars (Fogg, 1992). These approaches would take hundreds if not thousands or more years' to attain "habitable" conditions (although see Birch, 1992 and Taylor, 1992, for quicker results).

[16] Space Studies Board, 2005, p. 17.

The PPAC has noted that "a critical issue for the PPAC to address is how far the search for extant life should be pursued before Mars is contaminated by human missions.[17] Once humans are on Mars, "it will be compromised for future investigation of whether there was extant life on Mars."[18]

4. **Rationales for protection: scientific integrity? Moral or ecological imperative?**

Balancing pursuit of the goals of human exploration with objectives of planetary protection requires weighing the rationales for both. To date, planetary protection during robotic missions has been undertaken with the aim of preserving the integrity of science research. The ethics or morality of contaminating other celestial bodies is a concern that has been raised but has yet to be incorporated into public policy (in the case of provisions for planetary protection in the Outer Space Treaty, the interpretation of the rationale(s) for protection is somewhat unclear, as noted below). Can existing standards premised on maintaining scientific integrity accommodate the potential human contribution to contamination? Does human planetary exploration have implications for ethical considerations beyond those associated with robotic exploration, possibly compelling amendment of the standards to take ethical concerns into account?

4.1 The dominant theme: scientific integrity in the search for life elsewhere.

Some forty years' of in-depth discussion, largely but not exclusively within the scientific community, have evolved a set of internationally accepted protocols for planetary protection.[19] To date, the governing rationale for forward planetary protection has been interpreted as the maintenance of scientific integrity in investigations of the search for life elsewhere in the solar system. If other bodies have been contaminated during exploration activities, then the possibility arises of a "false positive" in identifying past or extant life.[20] In 1958, the National Academy of Sciences passed a resolution with the intent of mitigating this possibility: [21]

> The National Academy of Sciences of the United States of America urges that scientists plan lunar and planetary studies with great

[17] Meeting Notes, PPAC, 8-9 February 2005, pp. 5, 7-8.
[18] Meeting Notes, PPAC, 10-11 June 2005, p. 10.
[19] Rummel and Billings, 2004, offer a detailed overview of this history.
[20] For example, during a meeting of the PPAC, it was pointed out that the Apollo 12 crew retrieved a camera from Surveyor III, which had landed on the Moon two years previously. Bacteria on the camera had either survived on the Moon or the camera was contaminated during return and handling. See Meeting Notes, PPAC, 10-11 June 2004, p. 9.
[21] Space Studies Board, 2005, chapter 1.

> care and deep concern so that initial operations do not compromise and make impossible forever after critical scientific experiments.

In 1964, COSPAR issued a resolution affirming the objective of preservation of science integrity as a basis for planetary protection and has since set forth a set of protocols, most recently updated in 2005. These protocols are discussed further in the next section.

In 1967, the 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, Article IX), provided that

> State 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.

Whether this provision supports protection to safeguard science or to safeguard indigenous planetary environments for their own sake, independent of research, is not clear. However, the Space Studies Board documents analysis that concludes that interpretation of this provision is generally agreed to be a focus on science.[22]

The rationale for planetary protection policies in the US space program follows this interpretation. The policy directive, implemented by NASA and since 2002, benefiting in its administration from the advice of the PPAC, states that:[23]

> The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized. In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet or other extraterrestrial sources. Therefore, for certain space-mission/target-planet combinations, controls on organic and biological contamination carried by spacecraft shall be imposed in accordance with directives implementing this policy.

In a transmittal letter by the chair of the PPAC to the NASA Associate

[22] Space Studies Board, 2005, chapter 1.
[23] NASA Policy Directive: NPD 8020.7F Biological Contamination Control for Outbound and Inbound Planetary Spacecraft, Effective Feb. 19, 1999 until February 2009, at http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PD_8020_007F_&page_name=main (accessed June 2006).

Administrator for Space Science in 2005, Levy emphasizes that the policy is, at present, "expressly for the purpose of enabling scientific investigations while guarding the likelihood that the results of such investigations will be of the highest feasible scientific integrity over the course of the period of biological exploration."[24]

4.2 An occasional refrain: protection on the basis of ethics or moral imperative. The first U.S. conference on contamination associated with spacecraft returning to earth, held in 1964, convened representatives from NASA, the Department of Agriculture, the US Army, the National Institutes of Health, and other government and academic organizations. The conference report emphasized the "moral" responsibility of protection and urged US leadership towards that end (see Space Studies Board, 1965). In the early 1970s, Sagan called for "ecologically responsible" unmanned planetary protection of celestial bodies.[25]

Discussion both related to and independent of these policies has occasionally suggested or even urgently argued that consideration be given to additional or perhaps, alternative rationales for planetary protection. For example, Haynes (1990), McKay (1990), and Lupisella (1997, 2005) raise questions as to the ethics of contaminating the environments of space bodies.[26] Lupisella (1997) discusses "potentially biologically or ecologically intrusive" missions to Mars and points out that "it is questionable whether and how far humans have the right to interfere with extraterrestrial organisms." He urges that an international discussion, perhaps through auspices of the United Nations, consider these issues. He also notes that "moving away from the Western model of exploitation and colonization could be necessary."[27] Haynes wonders whether the philosophic and ethical implications of possible life on Mars call into question the validity of homocentric or geocentric worldviews. He raises the possibility of a new, cosmocentric ethics.[28]

Most recently, the Space Studies Board and the NASA PPAC have urged that high priority be given to opening dialog on what both groups refer to as ethical considerations. Both of these groups have also recognized that such discussions inherently involve a range of perspectives and for that reason, urge consultation with experts from a range of disciplines.[29]

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[24] Levy, 2005, p. 2.
[25] Sagan, 1993.
[26] In July 2005, a Russian astronomer filed a lawsuit against NASA claiming that the collision of the *Deep Impact* probe with the comet *Tempel 1* "ruined the natural balance of forces in the universe" (see http://www.thewbalchannel.com/pring/4687443/detail.html accessed May 2006).
[27] Lupisella, 1997, p. 90.
[28] Haynes, 1990, p. 177 and following.
[29] See Space Studies Board, 2005, chapter 8, and Meeting Notes, NASA PPAC, 8-9 February 2005, p. 2.

What might be among ethical concerns? One concern is the preservation of a pristine environment for its intrinsic value. Another relates to interference with an environment when little is known about its ecosystem. Just as there remain a large number of unsolved problems in understanding of human history and terrestrial environments, so too is there limited understanding of other planetary environments as ecosystems.

On earth, only recently have biologists and ecologists begun to understand the concept of full ecosystems. In light of new understanding, some policies are now seen as counterproductive. For example, by failing to take into account wildlife corridors (along which wildlife move during migration, breeding, and other lifecycles), land use zoning has disrupted the very ecosystems that zoning sought to protect. Could it be that in designating "special regions" on Mars, as COSPAR has done (more on this below) to protect areas where past or extant life may be more likely, will unintentionally fail in that goal? To take another example in this reasoning by analogy, Diamond (1997) documents "the unequal exchange of nasty germs between the Americas and Europe" as significantly more detrimental than firearms; he writes (p. 197): "Numerous as were the Native American victims of the murderous Spanish conquistadors, they were far outnumbered by the victims of murderous Spanish microbes." What might be the unintended consequences of the introduction of terrestrial microorganisms into extraterrestrial environments?[30]

5. Human exploration and planetary protection

Amending, redirecting, or extending protection protocols with the return to and expansion of human exploration inextricably depends on the nature of human involvement, in turn related to the rationale for human involvement. A cursory list (which does no justice to the more eloquent and extensive discussions of others) of reasons for human exploration includes:

Inherent destiny: "From the time of our birth, humans have felt a primordial urge to explore -- to blaze new trails, map new lands, and answer profound questions about ourselves and our universe." (from the NASA website at http//www.nasa.gov).

Science and understanding: "On Mars, robotic missions have found evidence of a watery past, suggesting that simple life forms may have developed long ago and may persist beneath the surface today. Human exploration could provide answers to some profound questions." (from the NASA website at

[30] I raise these questions in deference to planetary scientists who may well have some answers to them.

http//www.nasa.gov).

Technological gain "The benefits of space technology are far-reaching and affect the lives of every American… The exploration vision also has the potential to drive innovation, development, and advancement in aerospace and other high-technology industries." (White House Fact Sheet: "President Bush Announces New Vision for Space Exploration," 14 January 2004, at http://www.whitehouse.gov/news/relea ses/2004/01/20040114-1.html accessed June 2006).

Expanded industrial base: "A not-unreasonable scenario is a phase of highly subsidized capital construction followed by market-driven industrial activity to provide lunar products such as oxygen-refueling services for commercially valuable Earth-orbiting apparatus." (John Marburger on March 15, 2006 during the Keynote Address of the 44th Robert H. Goddard Memorial Symposium in Greenbelt, Maryland. At http://www.space.com/adastra/adastra_marburger_vision_060420. html accessed June 2006).

National security "The fundamental goal of this vision is to advance U.S. scientific, security, and economic interests through a robust space exploration program." (Marburger, see above).

Perpetuation of the human species: Human colonization of other planets could enable perpetuation of humans in the event of a catastrophe on earth

Absent in these statements is what, if any, accord to give to planetary protection. Policy analysts could respond that this absence is no surprise; planetary protection, like an environmental impact statement, is either implied as a necessity that is coincident with pursuit of these goals, or is irrelevant.[31]

Yet these reasons imply radically different approaches to planetary protection. *Perpetuation of the human species* would suggest that exploration take place with less, or even without, regard for protecting other planets for scientific integrity or ethical purposes. Stephen Hawking, the world-renowned British astrophysicist, recently told a news conference that the survival of the human race depends on space colonization that can continue without life support from earth. Hawking urged that colonization take place sooner rather than later.[32] Species protection

[31] An environmental impact statement is required for major development activities in the United States; discussion follows later in the paper.

[32] Hui, 2006. In the nonfiction best seller, *Catastrophe*, Seventh Circuit Court of Appeals Judge Richard Posner (2004) worries about four classes of catastrophes that could destroy most or all of the human race: natural catastrophes, such as an asteroid collision with earth or a pandemic;

would imply all-out effort to ensure a safe, habitable environment for humans, perhaps sooner rather than later.

Other goals – *technological gain, an expanded industrial base, national security* – may mean less or little regard for planetary protection in pursuit of these objectives, much like the early days of the industrial revolution and prior to the deeper regard many decisionmakers and the public now have for environmental assets. *Inherent destiny* would suggest that safeguarding scientific integrity by way of planetary protection matters insofar as it helps to answer questions about where we came from and where we are going.[33] "Map new lands" could mean that some regard be given to understanding planetary ecosystems for their own sake. But inherent destiny would also suggest a determination to send humans even in the extreme case that so doing would harm scientific integrity or interfere irreversibly with a Martian ecosystem.

The pursuit of human exploration for the purpose of *enhanced science and understanding* is broad enough to want planetary protection as a means of safeguarding science, but practically speaking, use of humans in addition to robots worsens the problem of contamination. If enhanced science and understanding were the sole objective, it may mean that robotic exploration is much preferred to sending humans, simply to minimize contamination.[34]

6. "Sustainable" human exploration of planetary ecosystems?

But is planetary protection really just an afterthought or even a nuisance as plans for human exploration unfold? As a broader community of the public eventually comes to give human exploration further thought, any relatively easy dismissal

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byproducts of technological progress, such as irreversible global warming that flipped; accidents due to unconstrained scientific exploration, such as uncontrolled replicating nanomachines or a catastrophic accident in a particle accelerator; and intentional catastrophes such as nuclear terrorism or bioterrorism. Posner doesn't mention exploration and colonization of other planets as a possible part of a solution if a societal goal is preservation of humans, but such a result is a direct possibility arising from his concern. If Hawking, Posner, and others are correct in their concern, then an all-out, Apollo-like expenditure of effort on human exploration for the purpose of colonization and self-preservation. This tack would give relatively larger weight to human risks than risk to indigenous Martian life.

[33] Questions such as these have been part of NASA's expressions for why it engages in space science.

[34] Involvement of humans also calls for the difficult decision about priority accorded astronauts in the event of backward contamination risks. In the case of the lunar samples returned by Apollo astronauts, the quarantine protocol stated: "The preservation of human life should take precedence over the maintenance of quarantine." If a command module had begun to sink during recovery operations when the module splashed down upon return to Earth, a major fire had broken out in the crew quarters of the receiving lab, or a quarantined astronaut suffered a medical emergency that could not be handled in the quarantine facility, the plan was to 'break quarantine' (Aeronautics and Space Engineering and Space Studies Board, 2002). These kinds of concerns argue strongly for an on-orbit space station return facility.

of planetary protection in pursuit of the goals of human exploration may be a flawed conclusion. The past years have brought at the highest levels of government a sensitivity to environmental concerns in an ever-industrializing world.

A watershed example is the convening by the United Nations, in 1983, of the World Commission on Environment and Development, known by the name of its Chair, Norwegian Prime Minister Gro Harlem Brundtland. The General Assembly resolved to:

> (i) "propose long-term environmental strategies for achieving sustainable development to the year 2000 and beyond;"
> (ii) "recommend ways in which concern for the environment may be translated into greater co-operation among developing countries and between countries at different stages of economic and social development and lead to the achievement of common and mutually supportive objectives which take account of the interrelationships between people, resources, environment and development;"
> (iii) help to define shared perceptions of long-term environmental issues and of the appropriate efforts needed to deal successfully with the problems of protecting and enhancing the environment, a long-term agenda for action during the coming decades, and aspirational goals for the world community…"

Another notable example of high-level attention giving precedent to environmental protection occurred at the annual Group of Eight (G-8) summit in France in June 2003. There, presidents and prime ministers of Canada, France, Germany, Italy, Japan, the Russian Federation, the United Kingdom, and the United States committed to build an integrated global earth monitoring system aimed at understanding and monitoring human influence on the environment and furthering sustainable development.

In the U.S., a longstanding discussion of the contribution of environmental assets to economic prosperity has even advanced the idea of monetizing them for their inclusion in the national income accounts (such as measures of Gross Domestic Product (GDP)).[35] Societies do value, and are willing to make sacrifices, to preserve or restore landscapes, ecosystems, habitat, wetlands, and other environmental goods.[36]

In the respect accorded to values well beyond those of *environmental* concerns,

[35] See Boyd, 2006, and references therein.
[36] Woodworth, 2006, offers some of the most recent discussion of the value of "natural capital" together with examples drawn from around the world in an article, "What Price Ecological Restoration?"

and relevant to the worry that planetary protection could interfere with the pursuit of science, societies willingly lose science research opportunities in decisions to forgo some types of research involving humans and animals. On the basis of ethical and other nontechnical considerations, life and death decisions are made by countries that are signatories to the Geneva Convention, and life and death decisions are seen by many as the outcome of social policies on abortion and the death penalty. The point of these examples is to admit the complexity of balancing preferences and values, and also to illustrate that complexity has not discouraged public discourse.

What, then, might serve as an enhancing principle for mediating the relationship between human space exploration and outbound planetary protection? The Brundtland Commission, in its final published report, *Our Common Future*, left as its most notable legacy an internationally agreed definition of sustainable development:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainable development in this sense signifies balancing economic and industrial development and environmental protection, explicitly with an eye towards the long term. The "long term" is key. It urges the present generation to consider its legacy for future generations. It allows, importantly, for the recognition that the future generation may be smarter. That is, with the benefit of technical advance, scientific understanding, and other investments, a next generation may know a lot more about how to develop. If so, then the present generation would want to avoid irreversible damage that precludes opportunities for the next generation. The present generation would also want to invest in opportunities to allow the next generation to get smarter.

If an objective such as "sustainable human space exploration" were to become accepted, what would be the pragmatic guidance for the sake of planetary protection? A necessary disclaimer is that terrestrial environmental protection and sustainable development, even if well intended, have had an uneasy relationship. Practices have evolved in fits and starts as a mix of deliberate and remedial actions and delicate and often ineffective balancing of competing objectives. Environmental protection has also been subject to sometime radical midcourse corrections taken after new information or understanding come to light, as well as realization that past practices have led in some cases to irreversible change or long-lived environmental problems. With these limitations in mind, several lessons from environmental management nonetheless offer some insights for further discussion of planetary protection.

6.1 The concept of value. Concepts of value are now routinely acknowledged for ecosystems and other public goods that are not normally exchanged in markets. These constructs include "preservation value," "intrinsic value," "existence value, " or "nonuse value." In other contexts values such as these are referred to as "aesthetic value," "bequest value," and "option value."[37] Reference to these values and methods for estimating them are widely used by government departments in the US and elsewhere when doing cost-benefit analysis of projects impacting, positively or negatively, on the environment.[38] Even if estimation of values such as these for planetary ecosystems is impossible, these concepts have legitimacy and credibility as constructs or even placeholders for expanding the value of planetary protection beyond scientific integrity. The "existence value," "nonuse value," or "option value" of a Martian ecosystem, say, are valid justifications for ecosystem protection even if most people will never visit Mars. These concepts facilitate a way to characterize a possible objective of what sustainable exploration seeks to protect.

6.2 Uncertainty. Without the luxury of a basis for specifying relationships and quantifying uncertainties, order-of-magnitude values and bounding likely values based on information that is at hand is often the best that can be done in implementing "sustainable practices." Expert elicitation, a statistical procedure by which likely values under different conditions are elicited from surveys of experts, is also an approach (and in fact, it is noted in NASA's recent Mars Exploration Program Analysis Group study).[39] In studies of human safety on Mars and on preventing forward contamination of Mars, National Research Council committee reports suggest some thresholds as terms of reference but note that these are based on "current understanding of the Martian environment and of terrestrial organisms." [40] The Space Studies Board in its 2005 recommendations also includes "identify scientific investigations that should be accomplished to reduce the uncertainty in (the study's) assessments."

Yet more information does not necessarily reduce uncertainty. While the

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[37] For example, see Freeman, 1993a, 1993b.

[38] Mitchell and Carson, 1989; Hanemann, 1994; Diamond and Hausman, 1994; Portney, 1994; Carson, Wilks, and Imber, 1994. Examples include valuation methods in proceedings following the Valdez spill, as well as in valuation of air and water quality, recreational opportunities in wilderness areas, and preservation or restoration of biodiversity (for example, wildlife habitat). These approaches have many critics, however. For a recent discussion, see Ackerman and Heinzerling, 2005.

[39] Beaty and coauthors, 2006. For general discussion, see report of "Expert Judgment: Promises and Pitfalls," a workshop and supporting documents at http://www.rff.org/rff/Events/Copy-of-Expert -Judgment-Workshop-Documents.cfm accessed May 2006, and Krupnick and coauthors 2006.

[40] Aeronautics and Space Engineering Board and Space Studies Board 2002; Space Studies Board 2005.

conventional decision model assumes that research reduces uncertainty, sometimes the result is that the underling model that was assumed is incomplete or wrong. Uncertainty can remain unchanged or it can grow. Studies of the accuracy of scientific understanding of technology on health and the environment have shown a large number of "true warnings" as well as a large number of "false alarms."[41] Unexpected effects of new technologies or late-recognized consequences of old technologies are not rare.

Some examples from terrestrial environmental protection illustrate this problem. In the case of land management, only recently has it become understood that some species often range along spatial corridors based on breeding, feeding, and migration cycles. This finding has in some cases altered the way in which land is typically parceled and zoned for development. Another example is resource and environmental effects that interact (such as relationships between wetlands and the amount and quality of surface and ground water). The latest trend is now "integrated" assessment that takes into account the interactions, feedbacks, and other relations among these components of an ecosystem. The most alarming examples are along the lines argued by analyses of the irreversible consequences of indiscriminate applications of technologies in new geographical environments for which the technology may be ill suited.[42]

In the case of planetary protection, new learning has led to changes in some conclusions rather than substantiation of them. An example of additional information leading to questions rather than answers is the experience from the Viking missions. The Viking landers in the 1970s explored locations on Mars that suggest a dry, barren environment hostile to life. Recent data indicate that Mars has multiple environments, with some suitable for life.[43] Another example, noted earlier in this paper, is recent advance in detecting extremophiles,[44] whereas previous understanding was limited to spore-forming bacteria.[45] As another example, a NASA study includes among its summary of findings from research about the Martian environment that contrary to treatment by COSPAR, the Martian polar regions may no longer be valid examples of special regions. According to this study, recent models suggest that previous results are overly optimistic regarding the potential for warming the polar cap material due to perpetual low temperatures and latent heat loss.[46]

Perhaps the lessons here for sustainable exploration are to beware the false

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[41] Mazur, 2004.
[42] Diamond (1997, 2005).
[43] Space Studies Board, 2005 and Beaty and coauthors, 2006.
[44] Extremophiles could also be a potential source of back contamination (see notes of the NASA PPAC meeting, 8-9 February 2005, p. 8).
[45] Space Studies Board, 2005.
[46] Beaty and coauthors, 2006.

promise that more information will bring answers or the assumption that human-centric technology and understanding are necessarily compatible with the ecosystems of other planets. These concerns also argue for a "go slow" approach (which of course, limited national budgets and planetary orbital mechanics enforce).

6.3 The desirability of an intergenerational perspective. An increasingly long list of environmental problems seems to be eluding any attempts at sound solutions. Nuclear waste and long-lived inorganic contamination of industrial and other sites have been a persistent source of concern. More recent concerns include the presence of accumulative pharmaceutical residues in air, water, and soil; and, in light of alarm over global warming, considerable uncertainty arising from proposed mitigation of greenhouse gas emissions through sequestration of carbon dioxide. Another newly emerging concern is a possible inability to remediate fully some types of contamination that could occur after a biological attack. The usual tools of analysis – tools such as discounting and risk assessment -- may be not be appropriate given the "forever-ness" of the problems and the fact that these problems transcend local and state boundaries to affect entire nations.

Early COSPAR protocol set twenty years as the period within which to limit the accumulation of possible forward planetary contamination. The NASA Mars Exploration Program Analysis Group finds that a 100-year period after a spacecraft arrives on Mars makes sense as the relevant interval at this point in understanding of the Martian environment. The recommendation is based on assessment of data and model results of dynamic processes in the Martian environment (for example, the time scale of ice deposition). The study notes, however, that some of these processes are particularly uncertain (an example is the probability of volcanic eruption).

Taking a long view can argue for the desirability of a "go slow" approach to planetary exploration if the goal is "no regrets" about contaminating other environments. To be sure, the timing of exploration can affect the rate of accumulation of new information (which may or may not reduce uncertainty, as noted above). However, the timing of exploration also affects the opportunity handed on to future generations. Those making the decision today may not be those facing consequences – or opportunities -- later. The next generation of researchers may have innovative solutions for mitigating contamination which contemporary researchers have not yet discovered. These solutions may be new types of preventive measures (for instance, new ways of sterilizing – a line of research identified as necessary by the Space Studies Board (2005). It may be that future generations could explore robotically or with human involvement at lower environmental cost than if the current generation "hurries."

6. 4 Environmental Impact Statements – unsatisfactory as a complete guide. The U.S. National Environmental Policy Act of 1969 (NEPA) requires federal agencies to prepare analyses of any of actions that significantly affect the quality of the environment. Environmental Impact Statements (EIS) have been produced for a host of activities, including oil and gas extraction, the construction of transportation corridors, and research in Antarctica. The process involves several steps (see box 1). The process also addresses a wide and complex array of environmental, health, and safety considerations (see box 2).

The NASA Mars Exploration Program Analysis Group includes in its recent recommendations that something like a "Mars environmental impact assessment" would be useful as a systematic way to analyze some special regions. The assessment would be a required part of early stage mission planning. [47]

Perhaps the environmental protection protocols set up for scientific research on Antarctica offer a useful precedent.[48] The primary purpose of the Antartic Treaty is largely political in that it is to ensure "in the interests of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord." To this end it prohibits military activity, except in support of science; prohibits nuclear explosions and the disposal of nuclear waste; promotes scientific research and the exchange of data; and holds all territorial claims in abeyance.[49] In 1991, a Committee for Environmental Protection was established by the signing of the Protocol on Environmental Protection for the Antarctic Treaty. The Committee is to safeguard Antarctica as a "special conservation area" and oversee the conservation of marine resources, the stewardship of protected areas and the conduct of environmental assessments for construction or other activity (such as for airstations, ice and rock drilling, field camps, telescopes). The Committee is concerned with the effect of activities on climate, weather, air and water quality, terrestrial, glacial, and marine environments, species preservation, and preservation of areas of biological, scientific, historic, aesthetic, or wilderness significance.[50]

In practice, environmental assessments are notoriously seen as a burden on development and are often conducted only perfunctorily, even though their outcomes include situations in which development is redesigned or halted

[47] Beaty, 2006, p. 54.
[48] The Space Studies Board report (2005) notes but does not explore this possibility.
[49] See information from the Scientific Committee on Antarctic Research (SCAR), a committee of ICSU and established to provide international, independent scientific advice to the Antarctic Treaty System at http://www.scar.org/treaty/ accessed June 2006.
[50] See the Committee for Environmental Protection under the Antarctic Treaty at http://www.cep.aq/ (accessed June 2006).

altogether. The steps in environmental assessment, by including opportunities for public comment (see box 1), could be useful to allow dialog among different perspectives on planetary protection. The wide range of topics in assessment (box 2), while specifically not relevant for planetary protection (at least in the near term!), encourages casting the net widely to list possible counterpart topics which might be relevant. By including concerns such as cumulative and induced impacts, the assessment exercise is supportive of "sustainable" development.

7. Conclusions

Sustainable space exploration, as defined in the spirit of the Brundtland Commission's definition of sustainability, offers a point of departure for the next generation of outbound planetary protection – that is, protection that accommodates human space exploration on other planets. A critical first step, however, is clarifying the reasons for human exploration of space. If the rationale is perpetuation of the human species by planetary colonization in anticipation of an earth-destroying catastrophe, then protection of other planets' ecosystems is likely to be highly unimportant. Exploration and habitation would proceed without regard for sustainability. If the rationale is maintenance of the scientific integrity of the search for life elsewhere, or if accord is to be given to moral or ethical imperatives to respect planetary ecosystems, then sustainable exploration enabling protection is the challenge for the public and decisionmakers.

Public discussion of these issues now, rather than later, could go far in helping to structure, and as importantly, adequately fund, planetary protection research, technological development, and planning.

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Box 1. **Steps in the U.S. National Environmental Policy Act Process for Considering Environmental Issues in Federal Agency Planning and Decision-Making**

Purpose of step:	*Formal reference:*
Description	**Proposed Action**
Public comment	**Notice of Intent**
	Comment Period
Draft to public	**Draft Environmental Impact Statement**
Public comment	**Public Review and Hearings**
Response	**Final Environmental Impact Statement**
Agency decision and actions to minimize environmental impacts	**Record of Decision**

Box 2. Topics Considered in U.S. Environmental Impact Statements
Air quality Biological resources (critical habitat and protected areas, wildlife movement corridors, threatened, endangered, or sensitive species; wetlands) Cultural resources (historic and cultural structures; archaeological sites, Native American sites) Geology and soils (mineral depletion, soil erosion, geologic hazards, hydrology and drainage) Hazardous materials and waste (releases, transport, storage, use, disposal) Land Use (conversion of farmland, existing land use plans, parks and recreational facilities) Noise (existing ambient noise, exposure of sensitive receptors to excessive noise, sonic booms) Health and safety (operational hazards, traffic and mechanical accidents, spills, fires, explosions) Socioeconomics and environmental justice (employment, disproportionate and adverse effects on minority and low-income populations) Transportation and infrastructure (traffic, parking, utilities, air traffic patterns) Visual resources (scenic vistas and resources, aesthetic quality of sites and sources of light and glare) Water resources (surface and ground water, waste water treatment facilities, floodplains, riparian issues) Cumulative impacts ("past, present, and foreseeable actions with potential for environmental impacts") Induced impacts (impacts that could arise from activities associated with proposed action and alternatives) Additional: Airspace

Commentary on

"Environmentally Sustainable" Space Exploration: Reconciling Challenges of Planetary Protection

By
Leslie I. Tennen
Law Offices of Sterns and Tennen
Phoenix, Arizona, U.S.A.

The Discussion Paper by Ms. Macauley raised several intriguing issues. It is, of course, inescapable and unavoidable that the exploration of celestial bodies will impact their natural environments.[1] In general, any impact upon the pristine environment of a celestial body could be considered as adverse, harmful, or disruptive. Manned and unmanned missions have altered the celestial environments by leaving the probes, parts, and other objects which have soft landed or crashed onto the surface.[2] Future exploration and use of the Moon and other celestial bodies inevitably will cause further disruption to natural environments.[3]

The environmental impact of space activities can be divided into biological and non-biological components. The international scientific community has addressed biological contamination, especially as it relates to the search for evidence of extraterrestrial life, or the remnants or precursors thereof. The diplomatic community has addressed the issue of environmental protection in broad, general terms, which do not distinguish between organic and physical contamination.

The interests in the protection of celestial environments transcend national boundaries and political philosophies. No individual state, or group of states, may have the necessary resources to adequately remedy the potential catastrophic injury that could occur to natural environs and indigenous life as a result of contamination.[4] Moreover, the interests in preserving pristine celestial

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[1] *See* Williamson, *Planetary Spacecraft Debris - The Case for Protecting the Space Environment*, in PROCEEDINGS OF THE 42ND COLLOQUIUM ON THE LAW OF OUTER SPACE 445 (2000).

[2] *Id.* at 446. *See also generally* M. WILLIAMSON, SPACE: THE FRAGILE FRONTIER (2006) [hereinafter referred to as "Williamson, Fragile Frontier"].

[3] *See* Vondrak, *Environmental Modification by Lunar Base Activities*, in 77 SCIENCE AND TECHNOLOGY SERIES, SPACE SAFETY AND RESCUE 1988-1989 375 (G. Heath ed. 1990).

[4] *See* Esquivel de Cocca, *International Liability for Damages Caused by Persons or Space Objects in Outer Space or on Celestial Bodies to Persons, Properties or Environment in Outer Space or Celestial Bodies*, in PROCEEDINGS OF THE 42ND COLLOQUIUM ON THE LAW OF OUTER SPACE 55 (2000)[hereinafter referred to as Esquivel de Cocca, "International Liability"].

environments are not static in time, as it is implicit that future generations have an interest to be protected in outer space, and the environments of Earth, the Moon, and other celestial bodies.[5] As Ms. Macauley observed, the challenge is to find a sustainable balance between the exploration and use of celestial resources, and the maintenance of the natural space environment.[6]

The discussion paper noted the development of the scientific approach to planetary protection, particularly in regard to forward contamination, leading to the most recent recommendations of the Space Studies Board.[7] The Objectives of this Workshop refer to the COSPAR planetary protection policy, and queries whether it may provide a useful example of possible approaches to the use and exploitation of outer space.

The evolution of the planetary protection policy has been a long and arduous journey, and whether or not it may be a useful example to follow must consider the efficacy of the policy in application. The subject of protecting natural celestial environments was first considered during the International Astronautical Federation Congress in Rome, in 1956. The following year, the U.S. National Academy of Sciences requested the International Council of Scientific Unions (ICSU, now the International Council for Science) to assist in the development of means to prevent contaminating celestial environments.[8] The ICSU, in turn, formed the *Ad Hoc* Committee on Contamination by Extraterrestrial Exploration (CETEX),[9] which considered celestial bodies to be *scientific preserves*.[10] In 1961, COSPAR assumed the duties of studying the potential for contamination by extraterrestrial exploration, and formed the Consultive Group on Potentially Harmful Effects of Space Experiments.[11]

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5 Cocca, Esquivel de Cocca, Sterns & Tennen, *Autonomous Settlements and Environmental Protection in the Law of Outer Space*, PROCEEDINGS OF THE 44TH COLLOQUIUM ON THE LAW OF OUTER SPACE 337 (2002).

6 *See generally* Williamson, Fragile Frontier, *supra* note 2, at chaps. 7 - 9.

7 Committee on Preventing the Forward Contamination of Mars, Space Studies Board, National Research Council, PREVENTING THE FORWARD CONTAMINATION OF MARS (2006), http://www.nap.edu/catalog/11381.html [hereinafter referred to as "SSB, Mars Contamination"].

8 *See* C.R. PHILLIPS, THE PLANETARY QUARANTINE PROGRAM: ORIGINS AND ACHIEVEMENTS 3 (1975), NASA Pub. No. SP-4902, U.S. GPO Stock No. 3300-00578; Stabekis, *History and Processing of Changes*, in REPORT, COSPAR/IAU WORKSHOP ON PLANETARY PROTECTION, Appendix C (2002).

9 Phillips, *supra* note 8, at 3; H.S. LAY & H.J. TAUBENFELD, THE LAW RELATING TO THE ACTIVITIES OF MAN IN SPACE, AN AMERICAN BAR FOUNDATION REPORT 189, n. 7 (1970).

10 Tennen, *Evolution of the Planetary Protection Policy: Conflict of Science and Jurisprudence?*, PROCEEDINGS OF THE 45TH COLLOQUIUM ON THE LAW OF OUTER SPACE 466 (2003), and 34 ADV. S. RES. 2354 (2003).

11 W.C. JENKS, SPACE LAW 34 (1965).

The COSPAR Consultive Group published its recommendations in 1964, and called for the application of *planetary quarantine requirements*.[12] Pursuant COSPAR, decontamination techniques were to be employed to reduce the probability of contamination of a celestial environment by a single viable terrestrial organism aboard any spacecraft intended for planetary landing or atmospheric penetration to less than 1×10^{-4}. The probability limit established by COSPAR for an accidental planetary impact by an unsterilized fly-by or orbiting spacecraft was 3×10^{-5} or less.

The probability of contamination was determined by the mathematical formula:

$$P(c) = m(i)(o) \cdot P(vt) \cdot P(uv) \cdot P(a) \cdot P(sa) \cdot P(r) \cdot P(g),$$ where:

P(c) = Probability of contamination

m(i)(o) = initial microbial burden at launch, after decontamination

P(vt) = probability of surviving space vacuum-temperature

P(uv) = probability of surviving ultra-violet space radiation

P(a) = probability of arriving at celestial body

P(sa) = probability of surviving atmospheric entry

P(r) = probability of release

P(g) = probability of growth[13]

These planetary quarantine requirements were to apply for the initial period of planetary exploration of ten years.[14] Nations were allocated specific fractions of the overall probability limits, which were apportioned by the recipient state among the missions planned to be conducted under its jurisdiction.[15] For interplanetary probes launched by NASA, the allocations of the probability of

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12 COSPAR Res. 26, 20 COSPAR INFO. BULL. at Annex 4 (1964).

13 Phillips, *supra* note 8, at 38.

14 Report, Committee on the Peaceful Uses of Outer Space, at 13, U.N. Doc. A/5785 (November 13, 1964). *See* Committee on Planetary Biology and Chemical Evolution, Space Science Board, RECOMMENDATIONS ON QUARANTINE POLICY FOR MARS, JUPITER, SATURN, URANUS, NEPTUNE AND TITAN 27 (1978)[hereinafter referred to as "SSB Recommendations"].

15 Sterns & Tennen, *Protection of Celestial Environments Through Planetary Quarantine Requirements*, in PROCEEDINGS OF THE 23RD COLLOQUIUM ON THE LAW OF OUTER SPACE 107 (1981).

contamination were:[16]

Mariner Mars	7.1×10^{-5}
Pioneer Jupiter	6.4×10^{-5}
Mariner Venus	7×10^{-5}
Viking	1×10^{-4}

The planetary quarantine requirements were subject to periodic re-examination and revision, often at the initiative of NASA.[17] In 1969, COSPAR made the first substantial revisions to the planetary quarantine requirements, and stated:

> as the basic objective for planetary quarantine of Mars and other planets deemed important for the investigation of extraterrestrial life, or precursors or remnants thereof, a probability of no more than 1×10^{-3} that a planet will be contaminated during the period of biological exploration . . . ending in 1988.[18]

This statement by COSPAR significantly altered the planetary quarantine requirements in two ways: first, it reduced the probability of contamination limit by a full order of magnitude; second, it limited the application of the quarantine requirements to "**Mars and other planets deemed important**" in the search for extraterrestrial life.

In 1978, the Space Studies Board concluded, through indirect lines of reasoning, that the probability of growth of a terrestrial organism in most extraterrestrial environments was so low that the probability of contamination was negligible, and thus it was not necessary to engage in any active decontamination techniques for those celestial bodies.[19] As a matter of policy, the assignment of minimal values to the probability of growth factor transformed planetary protection from a presumptive quarantine to the application of active bioload reduction techniques by exception.[20]

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16 NASA, Specification Sheets for U.S. Planetary Quarantine Program, Control No. 005 (1973) (prepared for COSPAR Meeting, Constanz, FRG, May, 1973).

17 *See, e.g., Outbound Spacecraft Basic Policy Relating to Lunar and Planetary Quarantine Control*, NASA Policy Directive 8020.7 (1967); *Outbound Planetary Biological and Organic Contamination Control*, NASA Policy Directive 8020.10A (1972); *Quarantine Provisions for Unmanned Extraterrestrial Missions*, NASA Hand Book 8020.12A (1976); *Biological Contamination Control for Outbound and Inbound Planetary Spacecraft*, NASA Management Instruction 8020.7A (1988); *Biological Contamination Control for Outbound and Inbound Planetary Spacecraft*, NASA Policy Directive 8020.7F (1999).

18 COSPAR Decision No. 16, 50 COSPAR INFO. BULL. 15-16 (July, 1969), *quoted by* Stabekis, *supra* note 8.

19 Space Science Board, Recommendations, *supra* note 14, at 27-28 (Appendix C).

20 *Id*. Nevertheless, the SSB continued to recommend that crafts intended for such celestial

In 1984, the abandonment of planetary quarantine requirements was completed, when the planetary protection policy called for bioload reduction and decontamination techniques to be employed only for certain missions to certain target bodies. This revised policy completely eliminated the determination of the overall probability of contamination. Indeed, for missions to target bodies which were deemed not to be of biological interest in the search for life, including the Moon, the policy did not require any planetary protection techniques to be utilized whatsoever, nor was there even any specific documentation required. For other target bodies, planetary protection constraints were to be determined on a case by case basis depending on the type of mission.[21]

While most celestial bodies in the solar system were deemed to not be important in the search for life, Mars has received special attention. In 1994, the planetary protection policy was revised with particular reference to missions to Mars. The 1994 policy revisions tied the utilization of decontamination and cleanliness controls to whether the mission objectives included life-detection experiments. That is, craft landing on Mars which carried life detection instruments were subject to Viking level sterilization, but landing craft without such life detection instruments were subject to substantially less stringent decontamination techniques.[22] These revisions to the policy continued the trend of reducing the number of missions which required Viking level sterilization.

During the 2nd World Space Congress in 2002, COSPAR restructured the planetary protection policy to classify missions into one of five separate categories, based upon the pre-determined "planetary protection status" of the target body, and the mission plan. The categories range from celestial targets which are "not of direct interest for understanding the process of biological or chemical evolution," to missions which involve the return of extraterrestrial samples to Earth.[23] An intermediate category has been introduced for planetary bodies which, while of interest concerning biological or chemical evolution, can be considered to present "only a remote chance that contamination by spacecraft could jeopardize future exploration."[24]

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bodies employ clean room techniques. It justified such recommendation not on planetary protection considerations, but on the basis that the use of clean rooms would reduce the possibility of growth of organisms which might compromise the functioning of the spacecraft or its payload. *Id*. at 15-16.

[21] COSPAR Internal Decision 7/84, *quoted by* Stabekis, *supra* note 8, Appendix C, at C-6.

[22] *See* AN EXOBIOLOGICAL STRATEGY FOR MARS EXPLORATION 49 (1995), NASA Pub. No. SP-530; *see also* DeVincenzi, *Planetary Protection Issues and the Future Exploration of Mars*, in 12 ADV. S. RES., No. 4, 121 (1992); D.L. DEVINCENZI, H.P. KLEIN & J.R. BAGBY, JR., PLANETARY PROTECTION ISSUES AND FUTURE MARS MISSIONS, NASA Conf. Pub. 10086 (1991).

[23] *See generally* Stabekis, *supra* note 8.

[24] Report, COSPAR/IAU Workshop on Planetary Protection, at chap. 1 (2002).

Pursuant to the current COSPAR policy, stringent bioload reduction requirements are imposed only for a limited range of missions, and only to a small number of target bodies, notably Mars, Titan and Europa. Viking level sterilization is mandated only for landing craft which are intended to conduct life detection experiments. Other landing crafts, and fly-by missions, are subject to lesser strictures. However, an exception has been made for the new category of "special regions," where it is believed that terrestrial life may propagate, or where indigenous Martian life may be present. For these "special regions," landing craft must achieve Viking level sterility, even where the craft is not intended to conduct life detection experiments.[25]
According to the SSB, the COSPAR policy was re-examined in light of current information regarding the science of Mars, the ability of extremophiles to survive in conditions which have expanded the understanding of the tenacity of life, new technologies and life detection techniques, improvements in methods to decontaminate and sterilize spacecraft, and other factors.[26] Perhaps the most significant factor mandating a re-examination is that the application of the COSPAR planetary protection policy has failed to achieve its essential purpose.

In accordance with the current COSPAR policy, the standard applicable to landing craft for Mars will allow for a pre-launch contamination level of 300 spores per square meter, and a total of up to 300,000 spores.[27] The situation is even more unsettling in relation to fly-by crafts. The probability of contamination limit of less than 3×10^{-5} has been abandoned, and crafts have been sent to Mars which were subject to relatively minimal decontamination techniques. No less than three separate unsterilized rovers have landed on the surface of the red planet, together with associated mission hardware[28] and not less than four other unsterilized spacecraft have been lost while approaching the planet and likely impacted the surface.[29] All seven of these unsterilized craft were in compliance with the applicable planetary protection policy in effect at the time of launch. By any objective standard the planetary protection policy based on classifications of mission type and target body combination has failed to prevent the contamination of Mars by terran space missions.

The Discussion Paper addressed the recommendations of the Space Studies

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25 *Id*.

26 SSB, Mars Contamination, *supra* note 7, at 2.

27 Debus, Runavot, Rogovsky, Bogomolov, Khamidullina & Trofimov, *Mars 96 Planetary Protection Program and Implementation for Mars Environment Preservation*, in PROCEEDINGS OF THE 40TH COLLOQUIUM ON THE LAW OF OUTER SPACE 220 (1998).

28 Sojourner, Spirit and Opportunity.

29 Mars Observer 1982-3, Mars Climate Orbiter 1998-9, Mars Polar Lander 1999 (deemed by NASA to be exemplary for planetary protection), and Nozomi 2003.

Board Committee on Preventing the Forward Contamination of Mars, of the National Research Council, which are a dramatic departure from the COSPAR policy. In essence, the SSB recommendations call for the entire planet of Mars to be considered as a special region, and thus subject to Viking level sterilization, until designated areas can be exempted for less rigorous decontamination techniques based on further exploration and experimentation. These recommendations are an important development in the protection of pristine celestial environments, and perhaps signal that the pendulum in planetary protection policies has reached its crest, and is now moving back in the direction of planetary quarantine.

The SSB recommendations invert the current COSPAR policy in which certain areas can be designated as a special region, and consider that Mars is a special region in its entirety. Areas may be designated for lesser levels of protection based upon more extensive scientific investigation than has been conducted to date. This is a welcome development, and is long overdue, however, this approach is the opposite of that expressed in article 7, paragraph 3 of the Moon Agreement,[30] wherein certain areas of the Moon may designated as international scientific preserves.

The SSB recommendations are specific to Mars and the indigenous environment, and have no direct application to the Moon or other celestial bodies of the solar system. This does not mean, however, that the COSPAR planetary protection policy has application to any particular celestial body. The COSPAR policy imposes active planetary protection techniques only for certain missions to the few bodies which are deemed to be important in the search for life, which other than Mars at the present time means only Titan and Europa. Even where applicable, the current COSPAR policy requires Viking level sterilization only for landing craft carrying life detection instruments.

The presence of a craft in a "special region," or the intention to conduct life detection experiments, should not be the determining factors in whether to apply strict bioload reduction requirements to an interplanetary spacecraft. The significant failures of both landing and fly-by craft sent to Mars in the recent past highlights that the lost space objects could have impacted the surface of the planet at unknown locations, including within "special regions." Thus, probes sent to Mars, even if not intended to conduct life detection experiments, or to land in a special region, or even to land at all, have carried a substantial risk of contaminating undetermined areas of the planet.

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[30] Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, *entered into force* July 11, 1984, 1363 U.N.T.S. 3, *text reproduced in* UNITED NATIONS TREATIES AND PRINCIPLES ON OUTER SPACE 27 (2002), *and* 18 I.L.M. 1434 (1979) [hereinafter referred to as the "Moon Agreement"].

From the perspective of planetary protection, the SSB recommendations must be viewed as a positive development, as they will, if implemented, reduce the probability of biological contamination of Mars. The implementation, however, is not certain, and the recommendations do not provide complete protection for celestial environments. Moreover, the SSB calls for the recommendations to be implemented over a lengthy ten year period. In addition, the recommendations must be adopted by the appropriate bodies to be implemented, which generally means NASA and COSPAR. As noted in the Discussion Paper, NASA has incorporated the past recommendations of the Space Science Board in its Policy Directives, which govern the activities conducted by the agency. NASA's previous acceptance of the SSB's recommendations has been the precursor to the formal adoption of policy revisions based thereon by COSPAR. Thus, it can be hoped that the current COSPAR policy will be subject to review and revision consistent with the current SSB recommendations.
NASA is conducting and planning a number of missions to Mars, but it is by no means alone. The European Space Agency, JAXA, and Russia all have conducted interplanetary probes, and India and China are waiting in the wings with their ambitious lunar programs. Russia has announced an especially ambitious plan to send a craft to the Moon which will release 12 penetrators to land near the Apollo 11 and 12 landing sites.[31] This raises the question whether there should be special protection for historic sites on the Moon, and for that matter, for other celestial bodies. Mark Williamson has raised the interesting prospect of the Apollo 11 landing site at Tranquility Base being designated as a destination for tourists, where individuals may view for themselves the famous footprints and other items left by the astronauts.[32] While the COSPAR planetary protection policy has little to no application to a tourist facility on the Moon, the *corpus juris spatialis* contains provisions with direct application to protecting pristine environments in the exploration and use of the Moon as well as other celestial bodies.

In March of 1962, Chairman Khrushchev wrote to President Kennedy about "heavenly matters," in which he stated: "It should, perhaps, be specified that any experiments in outer space which may hinder the exploration of space by other countries should be the subject of preliminary discussion and of an agreement concluded on a proper international basis."[33] This letter inexorably linked the issue of contamination of a celestial environment to the potential for such

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31 "Russia's Lunar Return," *Aviation Week & Space Technology*, June 5, 2006, p. 20.

32 Williamson, *Planetary Spacecraft Debris - The Case for Protecting the Space Environment*, 47 ACTA ASTRONAUTICA 719 (2000)(presented to the IAA/IISL Scientific-Legal Round Table on Protection of the Space Environment, 50th IAF Congress, Amsterdam, 1999).

33 Letter dated March 21, 1962, transmitting letter of March 20, 1962, from Chairman Khrushchev to President Kennedy, at 5, U.N. Doc. A/AC.105/2 (March 21, 1962).

contamination to interfere with the rights of states to conduct activities in space. The focus of Khrushchev's concern appears to be the impact contamination may have on the activities of other states, and not the disruption the contamination may have on the pristine celestial environment.[34]

The issue of contamination was taken up by United Nations Committee on the Peaceful Uses of Outer Space, and was addressed in the Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space in 1963.[35] Paragraph 6 of the Declaration provided that a state which has reason to believe that its planned activities may cause potentially harmful interference with the activities of other states, shall undertake appropriate international consultations before proceeding with the activities. Alternatively, a state which believes the activities of another state may cause such harmful interference may request consultations.

The Outer Space Treaty[36] incorporated the consultation structure of the Declaration, and included new legal provisions expressly directed to protecting the environments of Earth and celestial bodies in article IX as follows:

> . . . States 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 prevent 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. . . .

Thus, article IX addressed three distinct policy issues: forward contamination, back contamination, and harmful interference with the activities of other states.

The Moon Agreement also addressed these three policy issues, but separated the matter of environmental protection from the issue of interference with the activities of other states.[37] The Moon Agreement significantly departed from the Outer Space Treaty by placing an affirmative obligation on states to take measures to prevent forward and back contamination, and by specifying that adverse changes to the environment can be caused by harmful contamination

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[34] *See* Tennen, *supra* note 10.

[35] U.N.G.A. Res. 1962, *text reproduced in* UNITED NATIONS TREATIES AND PRINCIPLES ON OUTER SPACE 39 (2002).

[36] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, *opened for signature* January 27, 1967, 18 U.S.T. 2410, T.I.A.S. No. 6347, 610 U.N.T.S. 205, *text reproduced in* UNITED NATIONS TREATIES AND PRINCIPLES ON OUTER SPACE 3 (2002) [hereinafter referred to as the "Outer Space Treaty"].

[37] Moon Agreement, *supra* note 30, at arts. 3, 4, 5.2.

through the introduction of extra-environmental matter or otherwise.[38] As noted above, the Moon Agreement also contains a procedure by which:

> States parties shall report to other States parties and to the Secretary-General concerning areas of the Moon having special scientific interest in order that, without prejudice to the rights of other States parties, consideration may be given to the designation of such areas as international scientific preserves for which special protective arrangements are to be agreed in consultation with the competent organs of the United Nations.[39]

The Moon Agreement recognizes that the impact of activities on celestial bodies should be limited in relation to both disrupting or contaminating the environment, as well as in regard to possible alterations caused by the physical intrusion of the mission.[40] This recognition is expressed in Article 9, which provides that states establishing stations on the surface or subsurface of the Moon shall use only that area which is required for the needs of the station or other facility. Unfortunately, neither the Outer Space Treaty nor the Moon Agreement establish any procedures for reparation or compensation for damage or violation of these environmental provisions.[41]

The establishment of a lunar tourism industry will require an infrastructure consisting, at a minimum, of a transportation system to ferry passengers from the Earth to the Moon and back; a place for the space travelers to stay while at the tourist site, complete with various amenities and creature comforts; and tours, guided or otherwise, of the lunar environment and other attractions which beckoned the tourists. As a practical matter, no trip to the Moon would be complete without the obligatory souvenirs and gifts, which might be fabricated, in part, from lunar resources.[42]

The potential environmental impact of lunar tourism is apparent, and whether an area utilized by the venture is "required for the needs of the facility" must be left for future determination. Also for future determination are matters relating to issues of jurisdiction, appropriation, including so called private appropriation, and the form and methods of an international regime, which are being considered in other sessions of this Workshop. In addition, domestic licensing regimes will have a role to play, as the requirement that states authorize and

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[38] *Id*. at art. 7.1.

[39] *Id*. at art. 7.3.

[40] Cocca, Esquivel de Cocca, Sterns & Tennen, *supra* note 5.

[41] Esquivel de Cocca, *supra* note 4, at 51.

[42] Sterns & Tennen, *Private Enterprise and the Resources of Space*, IAF Paper No. IAC-05-E6.3.07 (2005).

continuously supervise the activities of their non-governmental entities in space provides a substantial mechanism by which a state can protect the environment. Perhaps most importantly, mention must be made of the obligation of states to conduct activities on the Moon and celestial bodies exclusively for peaceful purposes,[43] which is an essential and critical element for the protection of natural celestial environments.

Conclusion

The planetary protection policy has taken divergent paths in the scientific and legal communities. The law of outer space has been consistent in its philosophy, and modifications which have been made in terminology in legal instruments have expanded the scope of the planetary protection policy to encompass the three main considerations of preventing forward contamination, back contamination, and interference with the activities of states. The *corpus juris spatialis* has refrained from grafting exclusions, exemptions and exceptions to the policy. The same cannot be said of the scientific approach to planetary protection. What began as a presumption by CETEX that celestial environments are scientific preserves, has evolved into a selective policy applicable only to a limited subset of missions to a limited subset of target bodies.

The modifications of the planetary protection policy based on distinctions between celestial bodies which are or are not "deemed important for [the] investigation of extraterrestrial life,"[44] or whether or not they are deemed of interest for biological or chemical evolution,[45] and missions which do and do not contain life detection experiments, whether or not intended to land in a special region, unfortunately have failed to adequately protect Mars from possible contamination. As such, the policy may be deficient *vis-a-vis* international treaty commitments. Moreover the evolution of the planetary protection policy has lost sight of one of the basic propositions on which the policy was founded: a sterile celestial environment would be of major biological significance.[46]

The author wishes to express his gratitude to Patricia M. Sterns for her assistance in the preparation of this Commentary.

[43] Outer Space Treaty, *supra* note 36, at art. IV; Moon Agreement, *supra* note 30, at art. 3.
[44] COSPAR Decision 16, *supra* note 18.
[45] COSPAR/IAU Report, *supra* note 24.
[46] 1964 Report of COPUOS, *supra* note 14, Annex III, appendix 4, at 11.

Application of the Precautionary Principle to The Moon

By

Paul B. Larsen*

I. Introduction

A recent article in the American Journal of International Law ("AJIL") on application of the Precautionary Principle to Antarctica[1] engenders the idea that the Precautionary Principle could be applied usefully to activities on the Moon. The Precautionary Principle has been codified in several international agreements on the protection of natural resources. As expressed in Principle 15 of the 1992 Rio de Janeiro Declaration:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.[2]

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* The author teaches air law and space law at Georgetown University Law Center, 600 New Jersey Ave. NW, Washington DC 20001. E-mail: PBLSpace@aol.com. This comment was presented at the World Space Congress in Fukuoka, Japan, Oct. 17-21, 2005. The author acknowledges with gratitude helpful guidance received from Professor Robert V. Percival, Director, Environmental Programs, and Robert Stanton, Scholar, University of Maryland School of Law, from Professor Francis Lyall, University of Aberdeen Faculty of Law, University of Aberdeen, Scotland, and from Visiting Professor Bernhard Schloh, University of Pittsburgh Law School. Only the author is responsible for the views expressed herein.

[1] Kees Bastmeijer & Ricardo Roura, *Regulating Antarctic Tourism and the Precautionary Principle*, 98 AM. J. INT'L L. 763 (2004) [hereinafter Bastmeijer & Roura].

[2] United Nations Conference on Environment and Development, June 3-14, 1992, *Rio Declaration on Environment and Development*, princ. 15, U.N. Doc. A/CONF. 151/26 (Vol. I) (Aug. 12, 1992). *See, e.g.*, Convention for the Conservation of Antarctic Seals, June 1, 1972, 29 U.S.T. 441; Convention on the Regulation of Antarctic Mineral Res. Activities, June 2, 1988, 27 I.L.M. 859 (this Convention is not in force). *See also* Treaty Establishing the European Community, art. 174(2), Mar. 25, 1957, 2002 O.J. (C. 325), *available at* http://www.europa.eu.int./eur-lex [hereinafter European Community Treaty]:

> Community policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Community. It shall be based on *the precautionary principle*, and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay.

(emphasis added). *The Commission of the European Communities, Communication from the Commission on the Precautionary Principle*, at 4, COM (2000) 1 final (Feb. 2, 2000) [hereinafter Commission of the European Communities Communication], explains: [M]easures based on the precautionary principle should be, *inter alia*:

- *proportional* to the chosen level of protection,
- *non-discriminatory* in their application,
- *consistent* with similar measures already taken,
- *based on an examination of the potential benefits and costs* of action or lack of action

According to the Precautionary Principle,[3] States and their nationals conducting activities relating to natural resources must use extra caution when the result or outcome of the activity is uncertain. The Principle is particularly relevant to fragile environments.[4] The two authors of the AJIL article, Bastmeijer and Roura, observe that the Principle deals more with managing uncertain risks than with preventing known risks. They conclude that the Precautionary Principle applies to Antarctica.[5]

Antarctica is subject to the Antarctic Treaty of 1959, which has been universally accepted.[6] The Antarctic Treaty demilitarized Antarctica and made it into *terra communis*.[7]

The objective of this article is to examine whether the Precautionary Principle can also be applied to the Moon because the Antarctic Treaty[8] is closely linked to and served as the model for the 1967 Outer Space Treaty ("OST").[9] The Antarctica analogy was most forcefully made by United States President Eisenhower in his famous 1960 address to the United Nations General Assembly. He said:

> The nations of the world have recently united in declaring the continent of Antarctica "off limits" to military preparations. We could extend this principle to an even more important sphere. National vested interests have not yet developed in space or in celestial bodies. Barriers to agreement are

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(including, where appropriate and feasible, an economic cost/benefit analysis),

- *subject to review*, in the light of new scientific data, and
- *capable of assigning responsibility for producing the scientific evidence necessary* for a more comprehensive risk assessment.

3 Professor Robert V. Percival, Director of Environmental Programs at the University of Maryland, has researched the Precautionary Principle from a United States point of view; *see* Robert V. Percival, *Who's Afraid of the Precautionary Principle*, 23 PACE ENVTL. L. REV. 801 (2006). Professor Percival finds four main elements of the Precautionary Principle: a serious threat of irreversible damage; uncertainty about the impact of planned activities on the environment; the scope of the authority of the regulator; and the regulator's use of that authority. Wybe Th. Douma, *The Precautionary Principle in the European Union*, 9 REV. EUR. CMTY. & ENVTL. L., 132, 132 (2000), states that the Precautionary Principle applies when it is "unclear whether damage will occur at all or what causes existing damage." It applies when "risks are not quantifiable and can be referred to as potential risks." *Id*.

4 Bastmeijer & Roura, *supra* note 1, at 772.

5 *Id*.

6 Antarctic Treaty, Dec. 1, 1959, 12 U.S.T. 794, 402 U.N.T.S. 71 [hereinafter Antarctic Treaty]. Forty-seven States are parties to the Treaty. The Antarctic Treaty system includes the Protocol on Environmental Protection to the Antarctic Treaty which entered into force in 1998. Protocol on Environmental Protection to the Antarctic Treaty, Oct. 4, 1991, 30 I.L.M. 1455.

7 Common territory to which sovereignty cannot be acquired. *See* PHILLIP C. JESSUP & HOWARD J. TAUBENFELD, CONTROLS FOR OUTER SPACE AND THE ANTARCTIC ANALOGY 181 (1959).

8 Antarctic Treaty, *supra* note 6.

9 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter OST].

now lower than they will ever be again.[10]

President Eisenhower then proposed that, like Antarctica, outer space should not be subject to a claim of sovereignty, and that nations should not engage in warlike activities in outer space and on celestial bodies.[11] Like the Antarctic Treaty, the OST demilitarized the Moon and made the Moon *terra communis*.[12] The Moon is "the province of all mankind" and "not subject to national appropriation by claim of sovereignty."[13] *Ab initio*, it is notably the lack of right of national appropriation that weakens the absolute right of individual States to engage in lunar activities. In particular, lack of this right undermines the right to do anything in fragile areas because it may preclude other States from ever using those areas.

II. Reasons for Invoking the Precautionary Principle to The Moon

The reasoning behind application of the Precautionary Principle to Antarctica is that Antarctica is a fragile environment.[14] The Moon is possibly more fragile than Antarctica. All astronauts agree that outer space, including the Moon, is a very dangerous and unforgiving place that does not permit any mistakes to be made. Its fragile environment makes the outcome of lunar activities uncertain. It is particularly important to focus on uncertainties in making decisions about the Moon's environment because erroneous decisions about the Moon cannot be reversed. The Moon's fragility becomes an urgent question because several States plan exploration. For example, NASA's plans for moon exploration include the objective of permanent habitation; China and possibly India have new interest in Moon exploration; the European Space Agency ("ESA") plans lunar activities; private companies plan use of the Moon's minerals; and other private uses, such as manufacture and tourism on the Moon, are planned.[15] But the Moon is fragile: nothing grows on the Moon; it has no air; it is unable to "heal" itself after impact; craters from ancient asteroid strikes remain; and the footprints of the visiting United States astronauts will remain on the surface of the moon, unless disturbed by later lunar activity.

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10 Dwight D. Eisenhower, Address to the General Assembly, S. DOC. NO. 26, at 1009 (1st Sess. 1961) [hereinafter Eisenhower Address].

11 *Id*.

12 OST, *supra* note 9, at art. IV.

13 *Id*. arts. I, II.

14 *See* Bastmeijer & Roura, *supra* note 1, at 772.

15 Paul B. Larsen, *Current Legal Issues Pertaining to Space Solar Power Systems*, 16 SPACE POL'Y 139, 139-144 (2000). The United States' "vision" for economic development of the Moon was restated in a keynote address by White House Science Advisor, Dr. John Marburger, at the 44th Robert H. Goddard Symposium on March 15, 2006. Russia also plans economic development of the Moon. *See* Craig Cowalt, *Russia's Lunar Return*, AVIATION WK. & SPACE TECH., June 5, 2006, at 20.

III. Legal Basis for Applying the Precautionary Principle to Outer Space

When And Where Did States Agree On Application Of The Precautionary Principle To The Environment of The Moon? Nowhere in the space law treaties is application of the Precautionary Principle to the Moon expressly mentioned. However, the Antarctic Treaty System does not expressly adopt the Precautionary Principle either. [16] Legal authority for application of the Precautionary Principle to Antarctica is scholarly legal opinion that the Precautionary Principle can be read into the Antarctic Treaty System because the treaty system implicitly describes and incorporates the Principle. The two authors of the AJIL article, Bastmeijer and Roura, first ascertain that the Antarctic Treaty is accepted by all interested parties.[17] The treaty parties meet regularly in the Antarctic Treaty Consultative Meetings to implement the treaty system. Furthermore, "[a]pplication of the [precautionary] principle would be consistent with the proactive approach of the Antarctic Treaty System."[18]

A. Protection of Fragile Lunar Resources

If application of the Precautionary Principle to the Moon is linked to the fragility of the lunar environment, then we search for OST treaty provisions requiring caution in the use of the Moon's resources. General acceptance of the need to use caution is generally expressed in OST article V, which requires States to inform the United Nations of "any phenomena they discover in outer space, including the Moon and celestial bodies, which could constitute a danger to the life or health of astronauts." General acceptance of the need to use caution is also expressed in OST article IX, in which contracting States agree to "avoid harmful contamination" of the Moon.[19] Prospective harmful activities give States Parties the right to appropriate international consultations before beginning such activities as follows:

> [A] State Party to the Treaty [that] has reason to believe that an activity or experiment planned by [another Party] in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities . . . in the peaceful exploration and use of outer space, including

16 *See* Antarctic Treaty, *supra* note 6. Lluis Paradell-Trius, *Principles of International Environmental Law: an Overview*, 9 REV. EUR. CMTY. & ENV'T L. 93, 94 (2000) states that principles of international environmental law, such as the Precautionary Principle, are often drawn from many sources, in particular from soft law.

17 Bastmeijer & Roura, *supra* note 1, at 768.

18 *Id*. at 772.

19 Manfred Hintz, *Environmental Aspects of Settlement on the Moon and Mars—Planetary Protection*, 34 INT'L INST. SPACE L. 59, 61 (1991). Hintz questions the scope of harmful contamination, asking: "Does any change in the Moon's environment constitute harmful contamination or must it offend other states?" He assumes that the Treaty permits contamination below the level of harming the interests of other States. *Id*.

> the Moon and other celestial bodies, [may request consultation concerning the activity or experiment].[20]

Strict control by the States Parties to the OST of national activities on the Moon in OST article VI is another indication that the OST recognizes the fragility of the Moon.[21] States "bear international responsibility for national activities in outer space, including the Moon and other celestial bodies."[22] Other indications include OST article VII on liability for damages, article IX on state jurisdiction and control over their spacecraft, the Liability Convention,[23] and the Registration Convention.[24] The Aid to Astronauts Convention[25] is also relevant to this discussion. It was negotiated a year before the United States landed on the Moon in 1969. The United States and the Soviet Union were in a race to land on the Moon. Both were concerned about the uncertain dangers facing astronauts and cosmonauts on the Moon. In this treaty, they agreed on a procedure for assistance in the event that, through some unfortunate event, astronauts and cosmonauts are stranded on the Moon. The Aid to Astronauts Convention recognized the uncertainty of lunar activities in 1968.[26]

While no human beings had been to the Moon when the OST was drafted, the drafting of the 1979 Moon Treaty[27] has the benefit of the knowledge and experience of astronauts having faced the uncertainties of existence on and return from the Moon. The 1979 Moon Treaty specifically provides in Art 7(1):

> In exploring and using the Moon, States Parties shall take measures to prevent the disruption of the existing balance of its environment, whether by introducing adverse changes in that environment, by its harmful contamination through the introduction of extra-environmental matter or otherwise.[28]

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20 OST, *supra* note 9, at art. IX.

21 *See id*. art. IV.

22 *Id*.

23 Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 197 [hereinafter Liability Convention]. Damage to a space object on the Moon is subject to proof of fault.

24 Convention on Registration of Objects Launched into Outer Space, Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15 [hereinafter Registration Convention]. Space objects sent to the Moon must be registered.

25 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, Apr. 22, 1968, 19 U.S.T. 7570, 672 U.N.T.S. 119.

26 Paul G. Dembling & Daniel Arons, *The Treaty on Rescue and Return of Astronauts and Space Objects*, 9 WM. & MARY L. REV. 630 (1968).

27 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, Dec. 18, 1979, U.N. GAOR, 34th Sess., Supp. No. 46, 6.N. Doc. A/34/46 (1980), 14 I.L.M. 1434 [hereinafter 1979 Moon Treaty].

28 *Id*. art. 7(1).

The 1979 Moon Treaty is particularly clear about the fragility of the lunar environment. The treaty was negotiated in the United Nations Committee for Peaceful Uses of Outer Space ("COPUOS") just prior to 1979 at a time when COPUOS delegates had greater knowledge and greater understanding of the impact of actual human activities on the Moon. However, the 1979 Moon Treaty is weaker international law than the OST because the 1979 Moon Treaty, while in force, is not universally accepted.[29] Therefore, its greater significance is as evidence of the COPUOS delegates' (and thus the world's) awareness of the fragility of the Moon. The delegates found it necessary to establish a neutral information bank in the United Nations.[30] They decided to require States to limit their lunar activities as much as possible[31] and to keep the United Nations Secretary General informed.[32] They agreed on the need to revisit the issue of an international regime to govern use of the natural resources of the Moon. Finally, the delegates felt the need to strengthen the obligation to demilitarize the Moon.[33]

The general admonition against disrupting the existing environmental balance of the Moon is underscored by the 1979 Moon Treaty's article 7(3) provision that permits designating areas of scientific interest worthy of special protective arrangements.[34] Also on point is article 8(1), which states: "States Parties may pursue their activities in the exploration and use of the Moon anywhere on or below its surface, subject to the provisions of this Agreement."[35] The treaty requires the States Parties to be cautious of disturbing the balance of the environment. It is possible to construe the application of the Precautionary Principle to the Moon based on the combination of the four space law treaties. Such construction is more difficult if we remove the 1979 Moon Treaty from consideration. However, it is not a huge leap from OST article IX's obligation to avoid harmful contamination of the Moon to the 1979 Moon Treaty's more specific obligation to prevent disruption of the existing balance of the Moon's environment.

B. Protection for Scientific Investigation on the Moon

Preservation and facilitation of scientific investigation is an element of the Precautionary Principle and is also a major purpose of the Antarctic Treaty. That

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29 *See id*. Neither the United States nor Russia has ratified this treaty.
30 *Id*. arts. 5, 7. The information office is operated by the United Nations Secretary General through the Office of Outer Space Affairs. Visit http://www.oosa.unvienna.org for information about that office.
31 *See id*. art. 9.
32 *Id*. arts. 5, 7.
33 *Id*. art. 3.
34 *Id*. art. 7(3).
35 *Id*. art. 8(1).

element is clearly indicated in the Antarctic Treaty's articles II and III.[36] This leads Bastmeijer and Roura to conclude that application of the Precautionary Principle to Antarctica would harmonize with Antarctica's dedication to scientific investigation.[37] A similar conclusion may be made about application of the Precautionary Principle to the Moon and would harmonize with the Moon's dedication to scientific investigation. The 1967, OST, article I specifies that "[t]here shall be freedom of scientific investigation in outer space, including the Moon and other celestial bodies, and States shall facilitate and encourage international cooperation in such investigation."[38] In fact, scientific investigation of outer space is one of the main purposes underlying all the treaty and United Nations General Assembly declarations concerning the use of the Moon.[39]

C. Due Regard for Interests of Other States

States Parties agreed in the OST that the Moon and other celestial bodies "shall be the province of all mankind."[40] This principle emphasizes that use of the Moon by one individual State or by a group of States must take into consideration the interests of other States Parties. This principle is amplified by the 1979 Moon Treaty, article 11, stating: "[t]he Moon and its natural resources are the common heritage of mankind."[41] The 1979 Moon Treaty, article 11(5), continues that the States Parties shall "establish an international regime, including appropriate procedures" governing use of the Moon's resources.[42] This means that the Moon continues to be common property, as stated in the 1967 treaty, but that a detailed regime will be created in the future.

In lunar exploration and use, States Parties "shall conduct all their activities in outer space, including the Moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty."[43] The obligation to pay due regard permeates both the OST and the 1979 Moon Treaty.[44] The due regard requirement is consistent with application of the Precautionary Principle to the Moon because the effect of this principle to require

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[36] Antarctic Treaty, *supra* note 6, at arts. II, III.
[37] Bastmeijer & Roura, *supra* note 1, at 772.
[38] OST, *supra* note 9, at art. I.
[39] *See* Eisenhower Address, *supra* note 10. Note that the Commission of the European Communities Communication states: "[t]he implementation of an approach based on the precautionary principle should start with a scientific evaluation, as complete as possible, and where possible, identifying at each stage the degree of scientific uncertainty." Commission of the European Communities Communication, *supra* note 2, at 17.
[40] OST, *supra* note 9, at art. I.
[41] 1979 Moon Treaty, *supra* note 27, at art. 11.
[42] *Id*. art. 11(5).
[43] OST, *supra* note 9, at art. IX; *see* Hintz, *supra* note 19, at 60.
[44] *See* OST, *supra* note 9, at art. IX; 1979 Moon Treaty, *supra* note 27, at arts. 1, 2.

individual States to think twice before using the Moon's resources.[45] Thus, States using lunar resources must consider the interests of other States.

IV. Effect of Applying the Precautionary Principle

What would be the practical effect of applying the Precautionary Principle to the Moon? First of all, it must be emphasized that the Precautionary Principle differs fundamentally from an Environmental Impact Assessment.[46] The Precautionary Principle is an acceptance of the uncertainty facing lunar activities and the need to take this uncertainty into consideration in decision-making. While the Precautionary Principle is not absolute and does not prohibit activities on the Moon, it may find certain risks unacceptable. Application of the Precautionary Principle may lead to more thorough planning that includes the short and long-term effects of lunar activities. In the words of Bastmeijer and Roura:

> Generally speaking, a reasonable chance that serious adverse impacts will take place combined with questionable socioeconomic importance or available alternatives will push the "pointer" to requirements for additional precautionary measures or even to a "no go" or "not yet" decision.[47]

In Antarctica, the Precautionary Principle leads to improved evaluation of impact prior to the event rather than after the event, to prohibitions on activities where characteristics of the area are unknown, or to establishment of limits on certain kinds of activities. On the Moon, the Precautionary Principle might lead to similar consequences. It is clear that in Antarctica, the Precautionary Principle may be used to regulate tourism in sensitive areas. On the Moon, the Principle could be used for careful planning of manufacturing activities as well as tourism.[48] Entrepreneurs Sir Richard Branson and Burt Rutan are now soliciting reservations and plan to be in business by 2008 - Branson plans to build hotels on the Moon.[49] The Precautionary Principle may also lead to minimum levels of

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[45] See U.K. v. Ice., 1974 I.C.J. 3 (July 25), in which the International Court of Justice held that, on the high seas, States have "the obligation to pay due regard to the interests of other States in the conservation and equitable exploitation of these resources." This principle was adopted in UNCLOS, Dec. 10, 1982, 1833 U.N.T.S. 3, arts. 56-59.

[46] National Environmental Policy Act, 42 U.S.C. § 4321 (2006) [hereinafter NEPA]. For a discussion of whether NEPA applies to Antarctica, see Envtl. Def. Fund v. Massey, 986 F.2d 528 (D.C. Cir. 1993). *See* Jennifer A. Purvis, *The Long Arm of the Law? Extraterritorial Application of U.S. Environmental Legislation to Human Activity in Outer Space*, 6 GEO. INT'L ENVTL. L. REV. 455 (providing an excellent discussion of extraterritorial application of United States environmental laws).

[47] Bastmeijer & Roura, *supra* note 1, at 773.

[48] Fiorini, *The Sky's No Limit*, AVIATION WK. & SPACE TECH., Aug. 1, 2005, at 34 (predicting that 100,000 people will visit outer space during the first twelve years of operation of his spacecraft and that tourism will be the "foundation for human colonization of space").

[49] *Id*.

decontamination and other precautions before sending missions to the Moon.[50]

V. Enforcement of the Precautionary Principle

How would application of the Precautionary Principle to the Moon be enforced? Enforcement of the States Parties' concerns with the fragility of the Moon's environment through application of the Precautionary Principle would be mainly accomplished unilaterally by the States who are responsible for assuring that national activities are carried out in conformity with international law.[51] States Parties retain jurisdiction and control over their spacecraft, including persons onboard while on a celestial body,[52] and States Parties are internationally liable for damages caused by their spacecraft on the Moon.[53] Enforcement may also involve the Liability Convention[54] and the Registration Convention,[55] both of which are meant to identify and locate spacecraft that may cause damage in outer space.

States receive information about the lunar activities of other States through an information bank in the United Nations maintained by the Office of Outer Space Affairs ("OOSA"). States may raise issues of lunar activities during discussions in COPUOS. They may also request bilateral consultations under OST article IX. Under the 1979 Moon Treaty article 15, parties may "seek the assistance of the Secretary General, without seeking the consent of any other State Party concerned, in order to resolve the controversy."[56] States may also ask the International Court of Justice for enforcement of treaty obligations.[57]

VI. Conclusion

In today's early stage of exploration and use, we know very little about the Moon. States Parties have agreed to proceed cautiously and jointly, stating that "[t]he

50 Hintz, *supra* note 19, at 61.
51 OST, *supra* note 9, arts. III, VI.
52 *Id*. art. VIII.
53 *Id*. art. VII.
54 Liability Convention, *supra* note 23, at art. III.
55 Registration Convention, *supra*. note 24, at art. IV.
56 1979 Moon Treaty, *supra* note 27, at art. 15.
57 Statute of the International Court of Justice, June 26, 1945, art. 36, 59 Stat. 1031, *available at* http://www.icj-cij.org/icjwww/ibasicdocuments/ibcsictext/ibasicstatute.htm; IRVING SARNOFF, INTERNATIONAL INSTRUMENTS OF THE UNITED NATIONS 419 (United Nations 1997). Note that the European Court of Justice ("ECJ") enforced the European Community Treaty, *supra* note 3, at art. 174(2) (the Precautionary Principle). Case C-157/96, Nat'l Farmers' Union, 1998 E.C.R. I-2211; Case C-180/96, United Kingdom v. Comm'n, 1998 E.C.R. I - 2265. The Commission had banned export of beef from the U.K. to prevent the risk of bovine spongiform encephalopathy, and the ECJ sustained, holding that "[w]here there is uncertainty as to the existence or extent of risks to human health, the institutions may take protective measures without having to wait until the reality and seriousness of those risks become fully apparent." *Nat'l Farmers' Union*¸1998 E.C.R. I – 2211 at ¶ 63; *United Kingdom*, E.C.R. I – 2265 at ¶ 99.

exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind."[58]

Human activities in Antarctica raise more than environmental issues. They also raise such issues as search and rescue, economy of the tourist industry, and the politics of differing or irreconcilable claims of sovereignty. The Moon's future is also multifaceted, involving many kinds of human activities, ranging from tourism to colonization, mining, and appropriation of land by means of use or occupation. The space law treaties clearly did not envision the volume of human activities planned for the Moon. These increased lunar activities are reason to consider applying the Precautionary Principle to the Moon prior to environmental degradation. If the Precautionary Principle can be applied to Antarctica, then it can also apply to the Moon.[59]

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[58] OST, *supra* note 9, at art. I.

[59] This discussion of Application of the Precautionary Principle to the Moon does not consider domestic laws.

“Biological Contamination and Challenges to Planetary Protection: Comments on the Discussion Paper of Molly K. Macauley”

by

Hajotollah Vali
(McGill University, Canada)

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power point presentation

Biological Contamination and Challenges to Planetary Protection: Comments on the Working Paper of Molly K. Macauley

Hojatollah Vali
Departments of Earth & Planetary Sciences and Anatomy & Cell Biology
McGill University

The Exploration of Space

- **Space exploration** is the physical exploration of outer space - the politics, economics, science, and engineering behind space flight all fall under the auspices of space exploration
- there are many driving forces behind space exploration
- Molly Macauley delineates two compelling reasons in the exploration of space for which environmental aspects are a concern:

    1. *Perpetuation of the human species in the event of an Earth-destroying catastrophe*
    2. *Maintenance of the scientific integrity of the search for life elsewhere*

The Science of Astrobiology

- exploring the solar system and the Universe, and searching for life beyond Earth are some of driving forces behind space exploration at the ESA (*e.g.,* Aurora Program) and NASA (*e.g.,* Terrestrial Planet Finder)
- the science of Astrobiology is an interdisciplinary field, combining aspects of astronomy, biology and geology, which is focused primarily on the study of the origin, distribution and evolution of life in the universe
- the core concerns of astrobiology are research into the *origins of life* and the *search for life beyond Earth*

Mars and the Origin of Life

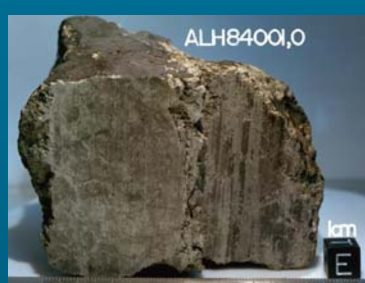
- a particular focus of current astrobiology research is the search for life on Mars
- there is no geologic evidence that the origin of life occurred on the Earth
- geological, geomagnetic, and geochemical evidence suggests that Mars was once much like Earth is today
- soon after Mars formed (4.5–4.2 Ga), the environment was possibly wet and temperate; water is considered to be an essential precursor to the development of life

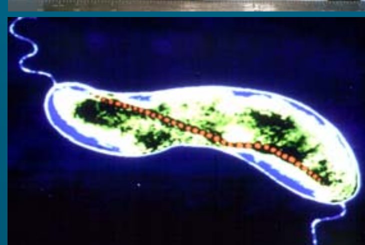
Evidence for life on Mars

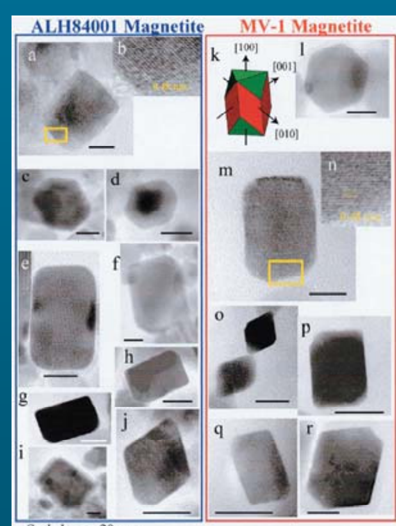
- while the NASA's Viking Missions to Mars in 1976 showed no evidence of extant life on the surface…

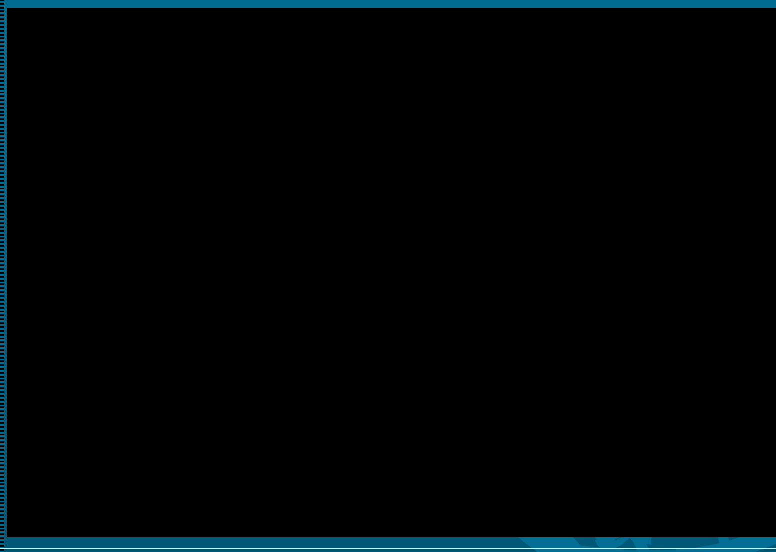
- …the investigation of Martian meteorite ALH84001 in 1996 suggested the possibility of ancient microbial life

Evidence of Biological Activity in Martian Meteorite ALH84001









Exogenesis

- one hypothesis for the origin of life is that life occurred elsewhere, such as on the planet Mars, and then transferred to the Earth – a theory known as *panspermia*

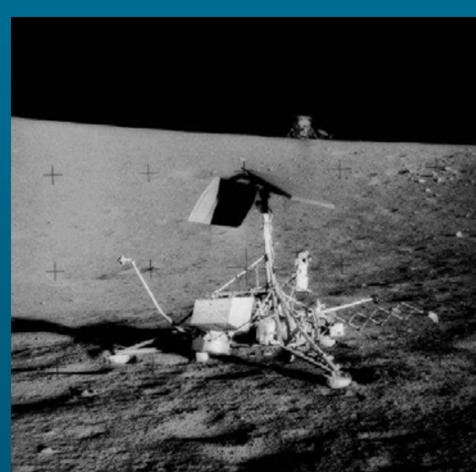
- alternatively, life originated on the Earth, but left no evidence as we don't have any rocks for the first billion years of Earth history, and then transferred to Mars

Mars and the Origin of Life

- if life was transferred between the planets, then Martian life, past and present, should have similar characteristics to early Earth life
- in contrast, if there was a second genesis, then life on Mars should be very different than life on Earth, and may, in fact, be quite difficult to detect or even recognize as life
- this points to the importance of planetary protection and of the potential for forward- and back-contamination arising from a Martian sample return mission

Interplanetary Transfer of Life

- in 1969, Apollo 12 astronauts Pete Conrad and Alan Bean brought back to Earth a piece of insulation from Surveyor 3, a lunar probe that landed on the Moon in 1967



Interplanetary Transfer of Life

- analysis revealed that the common bacteria, *Streptococcus mitis*, was unintentionally present inside the spacecraft's camera at launch
- around 50 to 100 of these bacteria survived dormant in this harsh environment for three years
- the bacteria had been freeze-dried in space, but were quickly revived once back on Earth

Life in Extreme Environments

Extremophiles

- an **extremophile** is an organism, usually unicellular, which thrives in or requires 'extreme' conditions that would exceed optimal conditions for growth and reproduction in the majority of mesophilic terrestrial organisms
- most extremophiles are microbes
- astrobiologists are particularly interested in studying extremophiles, as many organisms of this type are capable of surviving in environments similar to those known to exist on other planets

Extremophiles

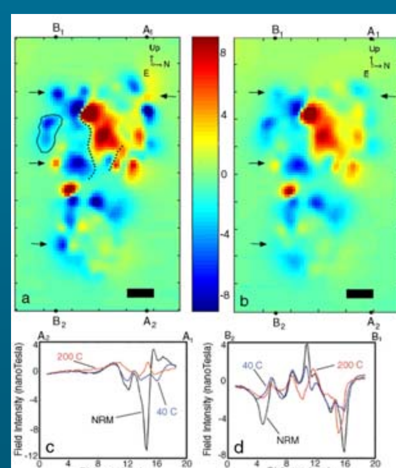
- for example, Mars may have regions in its deep subsurface permafrost that could harbor endolith (organisms that live in rocks) communities
- the subsurface water ocean of Jupiter's moon Europa may harbor life, especially at hypothesized hydrothermal vents at the ocean floor
- extraterrestrial life is expected to be largely microbial, and as conditions as forgiving as those found on Earth are rare in known planetary systems, extremophiles and their biology are thought to represent appropriate analogues to possible extraterrestrial life

Extremophiles

Alkaliphile: An organism with optimal growth at pH values above 10
Acidophile: An organism with a pH optimum for growth at, or below, pH 3
Barophile: An organism that lives optimally at high hydrostatic pressure.
Endolith: An organism that lives in rocks
Halophile: Requires salt for growth: extreme halophiles (all are archaea), 2.5 M to 5 M salt; moderate halophiles usually low levels of NaCl as well as 15 to 20% NaCl
Hyperthermophile: An organism having a growth temperature optimum of 80 °C or higher
Oligotroph: An organism with optimal growth in nutrient limited conditions
Psychrophile: An organism having a growth temperature optimum of 15°C or lower, and a maximum temperature of 20°C
Toxitolerant: An organism able to withstand high levels of damaging agents.
Xerotolerant: An organism capable of growth at low water activity, i.e., extreme halophile or endolith

Interplanetary Transfer of Life

- research has indicated that microorganisms could survive a journey from Mars to Earth
- in studying the magnetic properties of Martian meteorites and the composition of the gases trapped within them, it was found that ALH84001 and at least two of seven Martian meteorites were not heated more than a few 100ºC since they were part of the Martian surface nor did the Martian impact event heat them above 100ºC



(Weiss *et al.* 2000)

Interplanetary Transfer of Life

- more research is needed to understand whether interplanetary transfer of life could have been possible
- researchers have inventoried no more than a few percent of the total number of bacterial species on Earth
- groups of organisms that are genetically unrelated to the known life on Earth might exist unrecognized right under our noses

Conclusions

- space exploration is essential to advance our understanding of the origin of life
- the exploration of space should be science-driven
- planetary protection must be an essential part of space exploration, and research needs to be undertaken to recognize and characterize the nature of biological contamination

Planetary Protection, Contamination and the Precautionary Principle concerning the Moon, Planets and other Bodies of our Solar System

By

Klaus P. Heiss (High Frontier, USA)
and
Hojatollah Vali (McGill University, Canada)

Background

In discussing aspects of current policies of planetary protection for space exploration, Macauley (2006) suggests that defining a balancing test to achieve environmentally sustainable exploration requires a more systematic and thorough discussion of the rationales for space exploration. While there may be many driving forces behind space exploration, the author delineates two main compelling reasons in the exploration of space; (i) perpetuation of the human species in the event of an Earth-destroying catastrophe, and (ii) the maintenance of the scientific integrity of the search for life elsewhere. However, only in the latter case does the protection of the planetary ecosystem become an issue.

Substantial concerns, work and research has been done ever since the start of the Space Age – some even pre-dating it. For but one example: before the launch of Sputnik in October 1957 significant activities were initiated by the Soviet Academy of sciences with US counterparts along lines that even included considerations as to a total prohibition of sending objects into space until a better scientific understanding be gained as to exobiology – nowadays astrobiology [Steve Dick, NASA Historian].[1] Of course, Sputnik was launched but within a few months of these mutual visits and concerns and nothing adverse or dramatic has happened ever since.

A comprehensive summary of to-date's status in these and related matters is given in the US National Academy of Sciences report "The Astrophysical Context of Life" (2005)[2] and, related to a specific planetary body, the related report " The Quarantine and Certification of Martian Samples" (2002).[3] A

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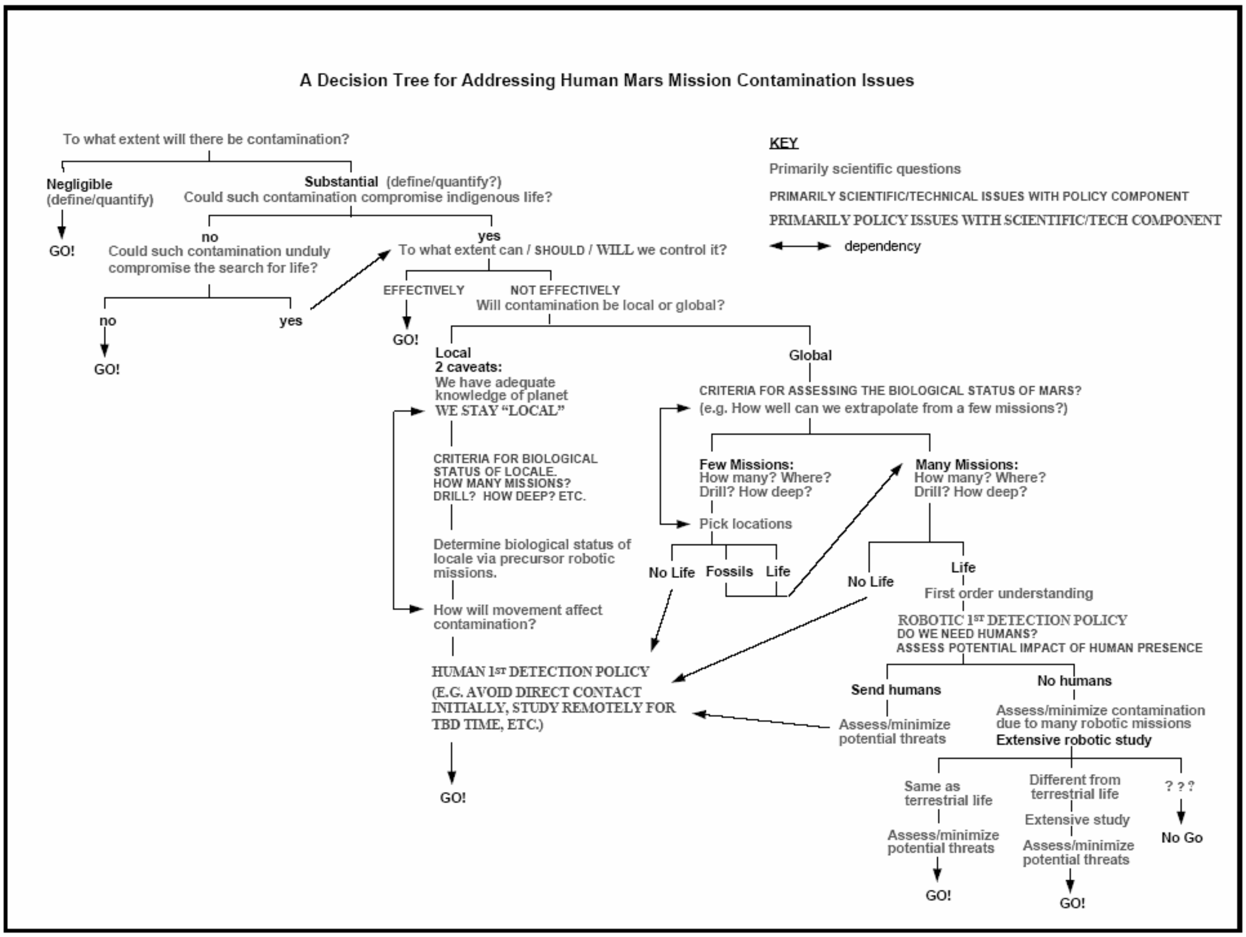
[1] Steven J. Dick and James Strick *The Living Universe: NASA and the Development of Astrobiology* (2004).
[2] National Research Council – Space Studies Board *The Astrophysical Context of Life* ISBN: 0-309-55151-x, National Academy Press, Washington, D.C., 94 pages (2005).
[3] National Research Council – Space Studies Board *The Quarantine and Certification of Martian Samples* ISBN: 0-309-0751-8, National Academy Press, Washington, D.C., 92 pages (2002).

comprehensive example on handling such issues has been given with the Lunar Receiving Laboratory.

Owing to the increased number of space missions to Mars in recent years and the potential for a sample return mission in the second decade of the century, there have been active discussions concerning planetary protection. The issue of cross-contamination, therefore, has become even more important and an essential part of any mission planning in light of recent evidence for the presence of water on Mars and the possibility of biological activity in the subsurface environment. In discussing human missions to Mars, Lupisella (2001)[4] presents an informal decision tree as one way to begin thinking about contamination issues (Table 1). According to his proposal, the potential for microbial life to survive, grow exponentially, evolve and modify (and sometimes destroy) the environment of Mars, warrants focusing carefully on biologically relevant contamination that may have indigenous life forms.

Table 1



[4] Mark Lupisella *Human Mars Mission Contamination Issues. In* Science and the Human Exploration of Mars. Michael B. Duke (Ed), Lunar and Planetary Institute LPI Contribution Number 1089 (2001).

It is essential to define the extent and degree of requirement for planetary protection. Consideration should be given to specific factors important for the specific missions. General environmental measures relevant to variety of issues on Earth should not be adapted for space exploration. Unfortunately, knowledge of the diversity of microorganisms on Earth is still in its infancy and requires comprehensive research to understand their interaction with different environments. Acquiring this database will enable us to better evaluate and design mission-specific planetary protection policies.

"Outward Contamination":

In the case of forward contamination of other heavenly bodies with life forms and matter from Earth, the basic concern is that "life" might be artificially introduced to other planets. While some might regard this as in fact an extraordinary, highly desirable event, particularly where no forms of life have been found, suspected or speculated about – nevertheless, the idea to ascertain that any such life indeed originated outside Earth and not from the Earth is of great scientific interest. Although it seems that with the considerable progress made in the past 50 plus years in determining the genetic origin of known types of species it should be a straight forward thing to determine the "origin" of such life, to the exclusion of any confusion, lest of course there are common life forms throughout the Solar System or the galaxy, in which case no 'contamination' took place.

However, it is important to emphasize that more ninety percent of the species on Earth have not been characterized. Therefore, additional research has to be undertaken to evaluate the significance of these unknown species on planetary protection.

Related thereto is the fear that life forms from Earth might extinguish in some predatory fashion 'indigenous" life: while within our Solar System we are not really concerned about the likelihood of "advanced life forms" being extinguished thereby, nevertheless would be desirable to have "pristine" proof and preservation of non-terrestrial life, however primitive its status. So a reasonable set of procedures should be observed to determine to the extent possible the likelihood of such primitive organism(s) and whether by any chance these might be affected or mutated adversely, if at all.

On the Moon, based upon our current knowledge, the surface is sterile and concerns and considerations of forward-contamination have reached about absolute zero. However, with the discovery of microorganisms living in rock four kilometers below the surface of the Earth, one has to be open to the possibility of biological activity below the surface of the Moon.

For Mars, Europa, Titan and beyond detailed planetary protection procedures are being developed and should be in place by say the early 2030's for human missions to Mars, the earliest possible date for such missions given the intricacies of celestial mechanics (2032 Earth-Mars opportunity) and space budgets. As to robotic missions, planetary protection procedures are in place and should be observed by all "Mars faring and beyond" countries and organizations.

A more relaxed view of the issues of "outward contamination" might conclude that

1. Life on Earth may actually have originated from outside Earth ("panspermia"), a recent hypothesis;
2. To date, no evidence of extant life within the Solar System outside of Earth has been found: further robotic missions should suffice to answer the question as to any presence (past or current) of life in diverse places throughout our system;
3. All indications to date are actually quite disappointing: total absence of "life" on the surface of the Moon and lack of direct indications of life on Mars, with some of the most primitive "tests" for such evidence as proposed in the 1960's still not made (measurement of any evidence of isotopes indicating such past organic activities);
4. Some places such as Europa, Titan, other moons, even the Rings of Saturn may be promising locations for evidence of extant or past life, but procedures already in place for robotic missions seem to suffice and human missions are somewhat off in the distant future (see Mars above).

So, as to human-caused outward contamination, more research must be undertaken to recognize and detect biological activity in all its forms and potential environments.

Backward Contamination

Visions of mass extinction have been speculated about in many a Hollywood movie. Hypotheses as to the origin of major plagues have also been associated with "extraterrestrial impacts" from time to time, including possibly the Great Plague of 1348. Hence special precautions have been taken in the past with regard to sample returns – robotic or human from space. Procedures and protocols are reasonably understood and followed.

However, some perspective on the issues at hand should be maintained:

1. Every year about **35,000 to 80,000 tons of "extraterrestrial" materials** hit the Earth, from small dust particles to more massive meteorites and from time to time even cataclysmic asteroids;
2. **Life on Earth** has been speculated to be of **extra-terrestrial** origin, or at least some of the life enabling components, such as phosphorus, an element extremely rare on Earth and providing the necessary backbone to DNA;[5]
3. Some of the materials "contaminating" Earth are directly of **Lunar and Martian** origin, thus contamination (panspermia) may already have occurred extensively in eons past;
4. Last but not least, the biological dangers of "contamination" with entirely novel forms of organisms are infinitely more real and present here **on Earth**, e.g., from **nanoorganisms** throughout tropical, sub-tropical and other biologically active areas that to date have been "dormant" but could be triggered at any time into truly cataclysmic plagues and diseases: certainly within our Solar System the likelihood of such "importation" is infinitely smaller – indeed negligible – when compared to extant terrestrial concerns.

Extensive protocols to guard against backward "contamination" have been developed and are being followed, possibly in an excess of precaution given the inherent violence and ongoing daily "contamination" of Earth and its surrounds over eons past and eons yet to come.

It has been proposed that any and all human missions beyond Earth-Moon space be first quarantined on the Moon until it is ascertained that indeed no backward contamination is likely. While giving one more reason to proceed forthwith with the exploration and settlement of the Moon as a first step toward expanding human presence into the Solar System, this may rank as one of the lower rational priorities of human space exploration over the next decades, if only for the rather distant prospects of human missions beyond the Moon in the foreseeable future until issues of human health of long term space flight beyond Cis-lunar space have been settled.[6]

On the "Precautionary Principle"

With lack of incontrovertible evidence for some feared or predicted disaster (danger) as of late the English language as enriched by this term (around

[5] National Research Council – Space Studies Board *Signs of Life – A Report based on the April 2000 Workshop on Life Detection Techniques* National Academy Press, Washington, D.C., ISBN: 0-309-08306-0, 68 pages (2002).
[6] Todd O. Stevens and James P. McKinley, "Lithoautotrophic Microbial Ecosystems in Deep Basalt Aquifers," p 450-454 v 270, *Science*, (1995).

1988).[7]

"The precautionary principle, a phrase first used in English circa 1988, is the idea that if the consequences of an action are unknown, but are judged to have some potential for major or irreversible negative consequences, then it is better to avoid that action. The principle can alternately be applied in an active sense, through the concept of "preventative anticipation", or a willingness to take action in advance of scientific proof of evidence of the need for the proposed action on the grounds that further delay will prove ultimately most costly to society and nature, and, in the longer term, selfish and unfair to future generations. In practice the principle is most often applied in the context of the impact of human civilization or new technology on the ecosystem, as the environment is a complex system where the consequences of some kinds of actions are often unpredictable.

The formal concept evolved out of the German socio-legal tradition that was created in the zenith of German Democratic Socialism in the 1930s, centering on the concept of good household management. In German the concept is Vorsorgeprinzip, which translates into English as precaution principle. The concept includes risk prevention, cost effectiveness, ethical responsibilities towards maintaining the integrity of natural systems, and the fallibility of human understanding. It can also be interpreted as the transfer of more generally applied precaution in daily life (e.g. buying insurance, using seat belts or consulting experts before decisions) to larger political arenas. Operating a large military apparatus for example also is the practical application of precaution against hypothetical threats."

Of course, all of this newfound "caution" presupposes what the dangers lurking "out there" are. To take but one example, Global Warming vs. Global Winter: as late as the 1970's a scientific consensus was developing as to the imminent dangers of a Global Winter and the outbreak of the next ice-age (by some estimates mankind already may have avoided such a disastrous event a few thousand years ago, see Scientific American …). Until but a few years ago three rooms in the National Museum of Natural History in Washington DC were adorned with the dire consequences of such a global cooling with all types of calamitous consequences ranging from hunger and pestilence to worse.

Today a similar "consensus" seems to have developed as to the opposite: the imminent or already started human caused change in global climate causing Global Warming, with many identical catastrophic predictions as to the consequences thereof on mankind.

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[7] From Wikipedia, the free encyclopedia.

So: what is one to do under the “Cautionary Principle”? Had the Precautionary Principle ideologues rules in ages past then the joys of adaptation would be replaced by a persistent dwelling in the caves until we would have figured out the true dimensions of the issues and problems at hand. Indeed it is the ability to adapt, not the flight into frightened inactivity, that accounts for evolution and the very predominance of mammals – and mankind – today.

A further note of caution: human behavior in daily life and in a myriad of policy decisions already is overly “cautious” and risk averse, rather than risk neutral – a neutrality that would conform to abstract, mathematical rationality. Daniel Bernoulli’s observation of the St. Petersburg Paradox in the 18th century and its explanation by Carl Menger and others of the “Austrian School” in the 1930’s forms the very foundation of utility theory and human behavior. If anything, “rational” behavior and public policy might want to “counterbalance” the exceedingly cautious behavior of individuals.

If one does not know what the facts and the dangers are – of one type or the exact opposite – fires or floods, ice ages or human caused global warming explosions, etc. – the “Precautionary Principle is soon seen to be devoid of any operational use other than academic and late night talk shows.

Applied to space exploration, the Precautionary Principle may dictate exactly two opposite actions, behaviors and “moral imperatives”:

1. The **“Pest and Brimstone Contamination”** of the universe by mankind warners, mandating on “moral grounds” not to spoil the pristine-ness and beauty of space until we are sure that no damage will be caused by our expansion into the Solar System and beyond into our galaxy;
2. The “**Space Colonization Brigades**” ready to conquer one and all, even irrespective of the many very serious human health, technology risks and simple ignorance of pendant issues; and, in-between
3. The “**Go into Space to Survive**” group, with its latest advocate in Stephen Hawking and all the attendant attention and support his view have received in the global media.[8]

Based on thousands of years of history and mankind’s persistent quest to expand into and beyond new frontiers and into the unknown the “historical imperative” for sure seems to be ingrained in mankind and mandate such an expansion. This might be further “dictated” by the empirical evidence of the extreme violence

[8] Stephen Hawking, Stephen Hawking's Universe : The Web companion piece provides detailed explanations of the most important ideas and developments in human understanding <www.pbs.org/hawking/html/home.html>.

permeating the galaxy and the universe, which would seem to indicate a happy coincidence of the “historical” the “moral” and the “precautionary” principles and mandates.

But then again, this is the view of the precautionary principle of but one (K.H.) and perhaps some of the workshop participants.

Rapporteur's Notes

SESSION 3 – ENVIRONMENTAL CONCERNS

Chairperson: ***Lubos Perek*** (Czech Academy of Sciences, Czech Republic)
Rapporteur: ***Tanja Masson-Zwaan*** (IISL, The Netherlands)

This session addressed emerging environmental concerns regarding the exploration and exploitation of outer space resources, including those of the Moon and other celestial bodies, especially the question whether there is a need for outer space environmental protection laws and policies, and what environmental impact assessment studies are necessary or should be envisaged for precautionary purposes prior to the development of the space industry.

1. Discussion Paper: *Molly Macauley* (Resources for the Future, USA) *(presented by the rapporteur)*

Ms. Macauley explained the distinctions between backward and forward contamination and the importance of the protection of samples from being contaminated before examination. Her paper focused on forward contamination related to human exploration activities.

She explained that it is the rationale for protection that determines the measure of protective action. The rationale in most cases is *scientific integrity*, but sometimes also based on *ethics* and *moral* reasons.

In the 60s, the first standards were elaborated by COSPAR, NASA, ESA. Later on, COSPAR changed the standards and the requirements depended rather on the type of the mission and the destination: the protection recommendations vary according to the kind of mission, e.g. with or without the aim to make direct contact, with or without intended return to earth, etc. In 2002, a new category of 'special regions;' was created, such as Mars, where more stringent requirements had to be met.

Recently, some new considerations have entered the arena; on the one hand, more information is available, for instance about the existence of *extremophiles*. On the other hand, new plans for (human) exploration have been elaborated. Obviously, human exploration presents more risks, and current protection policies do not address human exploration.

The degree of planetary protection is also related to the rationale for human exploration itself: e.g. our inherent destiny to explore, the desire to conduct science, technological gain, national security, preservation of the human species

in case of a disaster on earth, etc. The author concluded that the desirable level of planetary protection as per these goals would in most cases be rather low.
Ms Macauley suggested that what is needed is *sustainable human space exploration*, so as not to preclude exploration by future generations under better conditions and with better information at their disposal. She recommended a "go-slow" approach as the best option for current human exploration initiatives, and suggested that the adoption of a Protocol on environmental protection, similar to the one adopted in the framework of the Antarctica treaty, may be a first step.

2. Commentator 1: *Leslie Tennen* (Sterns & Tennen, Phoenix, USA)

Dr. Tennen provided a historical overview of the evolution of planetary protection initiatives since the 1950s. He explained COSPAR\s planetary quarantine requirements, with contamination being determined by mathematical formulas. These requirements were reduced significantly over the years, and moreover were applied only to certain missions. As a matter of fact, planetary protection became the exception, rather than the rule. It only applied to missions that included life-detection experiments, as opposed to the earlier requirements of sterile conditions such as were applicable to missions through Viking. Later on, in 2002, COSPAR elaborated 5 categories of missions; the requirements apply to a limited range of missions to a limited number of targets, with exceptions for certain specific regions like Mars, where the requirements apply irrespective of the aim of the mission. The recent recommendations of the Space Sciences Board of the National Academy of Sciences to consider the whole of Mars as a special region is welcome and appropriate, but is too limited in scope.

Unfortunately, the COSPAR policy failed to achieve its goals; seven missions to Mars complied with the imposed requirements, but nevertheless may have caused significant contamination. This means that the requirements do not sufficiently protect against possible harm.

Dr. Tennen then discussed the law of outer space, which also addresses the issue of planetary protection. Special mention was made of Article IX of the Outer Space Treaty, which in fact addresses three policy issues: forward contamination, backward contamination and interference with activities of other states. The Moon Agreement also addresses the issue but separated the first two from the latter.

His conclusion was that space law had been consistent in its philosophy regarding the issue of planetary protection, while the scientific approach had lacked this consistency; its policies have become selective and apply only to a limited set of missions and a limited set of target bodies. The policies have lost sight of the basic idea of the biological significance of a sterile celestial environment and peaceful uses of outer space.

3. **Commentator 2:** ***Hojatollah Vali*** **(McGill, Canada)**

Dr. Hojatollah Vali explained the science of astrobiology as an interdisciplinary field focused on the study of the origin, distribution and evolution of life in the universe. A core concern is the study of the origins of life; the author held the view that life may be a common phenomenon in the universe. He explained that the early planetary development of Mars was similar to Earth, and that early Mars may have had a warmer and wetter climate, such that liquid water could have persisted on the surface of Mars. Regarding the possible evidence of life on Mars, he made reference to the Viking missions in 1976, which was excellent in terms of technology, but lacked sufficient scientific knowledge about the development and existence of life in extreme environments, e.g., extremophiles (micro-organisms). There may be groups of organisms that are genetically unrelated to the known life on Earth that might exist unrecognized right under our noses. He then discussed the investigation of Martian meteorite ALH84001; this was the first time that minerals (e.g., magnetite) were used as evidence of ancient biological activity. The minerals were created by very sophisticated micro-organisms (magnetotactic bacteria).

We can ask ourselves whether life originated on Mars and was transferred to Earth; a theory called panspermia. If that were the case, we would have little problems to recognize this life, as we would be composed of the same basic DNA. If life on Mars development on its own, a kind of second genesis, it might be more difficult to recognize or detect as life. A second genesis would tell us that life in the universe is common, would provide us with a comparative biochemistry and give us clues about the early Martian environment. Early life, however, could have originated on Earth, left no evidence, and been transferred to Mars.

As to the question whether the interplanetary transfer of life is possible, Dr. Vali mentioned the example of the common bacteria, Streptococcus mitis. In 1969, Apollo 12 astronauts brought back to Earth a piece of insulation from Surveyor 3, a lunar probe that landed on the Moon in 1967. Analysis revealed that around 50 to 100 of these bacteria were unintentionally present inside the spacecraft's camera at launch and survived dormant on the harsh environment of the Moon for three years. The bacteria had been freeze-dried in space, but were quickly revived once back on Earth. In the case of extremophiles, this could be extremely dangerous, as they can easily adapt to the extreme environments of space and other planetary bodies. Extremophiles could survive transport between Mars and Earth by a meteorite. It is very unlikely that extremophiles could be transferred to other planet in our solar system by space vehicles.

Dr. Vali's conclusion was that we more research towards understanding the nature of micro-organisms existing on Earth before we can safely conduct further space exploration.

4. **Commentator 3:** ***Paul Larsen*** **(Georgetown University Law Center, USA)**

Prof. Larsen discussed the possible application of the 'precautionary principle' to the Moon. He drew an analogy with Antarctica, to which the principle had also been found to apply in a recent article in AJIL. The principle implies that in case of damage that is serious and irreversible, the actor has a responsibility to study the outcome of his activity, and if that outcome remains unknown, to refrain from it. Although the principle is not specifically referred to, Prof. Larsen held the view that it can be 'read into' the Outer Space Treaty, for instance Articles I, V, VI and IX. It is also addressed in the Moon Agreement. Regarding the question of how to enforce the principle, Prof. Larsen believed this should be done unilaterally, by the States responsible for the activities concerned. The effect of the application of this principle would be that more thorough planning of missions would take place, and may lead to a decision not to go. Thus, it would result in improved evaluation before, instead of after the mission, and a prohibition to conduct the mission if its effect would remain unknown. Prof. Larsen concluded that if the precautionary principle applied to Antarctica, it probably should apply to the Moon as well.

5. **Commentator 4:** ***Howard Baker*** **(Department of Justice, Canada)**

Dr. Baker indicated that there is a clear need for planetary protection, but it is not clear to what extent legal, scientific and political aspects must be taken into consideration. He addressed three main topics in his comments.

Firstly, *environmental ethics*. Dr. Baker explained that human behaviour is based on moral codes, and expressed the desire to develop such a code based on respect for nature; all living things and their environments have a right to exist.

Secondly, he discussed *international environmental law* and indicated that 'sustainable development' is one of its four principles, but the least important for human activities in space. Sustainable development may call for a restraint on human activity in order to protect the weak. The other three principles were then discussed, i.e.

- 'common concern'; after all, ecosystems, including those on the moon and mars, know no borders;
- 'good neighbourliness'; the principle of not disturbing others, of limiting

the use of resources in order to avoid harmful effects;
- 'precautionary principle'; as discussed by Prof. Larsen, amounting to not carying out an activity if it causes irreversible damage to others.

Thirdly, he addressed *environmental protection in international space law* and specifically Article IX of the Outer Space Treaty; unfortunately it only concerns scientific purposes and not the protection of the space environment.

As to what must be done next, Dr. Baker suggested drafting an environmental protocol to Article IX, similar to the Madrid Protocol adopted in the framework of the Antarctica Treaty. It could consist of a framework agreement, complemented by a specific agreement for specific activities, such as mining on the moon, mars exploration, space trafic management, etc.

6. Discussion

Regarding the paper by Ms Macauley, **Mr. Ghafoor** stressed that planetary protection measures would increase the cost of planetary exploration considerably and this must be kept in mind. He also held the view that as we now have an opportunity of obtaining answers to very fundamental questions, we should try to go forward, taking into account of course all the necessary precautions.

Mr. Murthi indicated that it will be very difficult to come to an agreed legal definition of the term "sustainability", but that a clear legal formulation of what it means exactly was dearly needed. The difficult question is when something is 'irreversible'.

Prof. Kopal agreed, and stated that the Outer Space Treaty and the Moon Agreement do not suffice, although they do contain some useful elements of course. Moral and ethical reasons alone also do not suffice. Possibly, a new legal framework may be called for, developing and elaborating standards, similar to the Antarctica legal framework; perhaps we should strive for a new treaty for the protection of the space environment.

Prof. Mani suggested to keep in mind that Article 3 of the Outer Space Treaty specifically confirms the applicability of international law to activities in outer space, so we should look at the entire plethora of international legal principles that could have an impact on planetary protection.

Dr. Heiss stated that nature is cruel, not moral, and that we must be aware of change, and adapt to it, but not try to prevent or stop it. It is man's destiny to conquer nature, this is our moral imperative. Not to go would amount to a betrayal of future generations, in his view. [*Comment by Dr. Heiss*: See the paper drafted by Dr. Heiss and Dr. Vali on the issues of “contamination”, “forward” as well as “backward”. As regards the latter [backward contamination], recent insights as to an estimated 400,000 plus as yet undiscovered – e.g. noted in the September issue of Scientific American - dangerous, hitherto unknown pathogens in the Brazilian tropical forests alone would indicate that the “precautionary principle” has a preponderance of applications down here on Earth, before wasting valuable resources on imagined problems.]

Prof. Gabrynowicz countered that nature consists of both the base aspect of human nature and its highest aspects. Humankind can also choose to strive to realize higher aspirations, and strive for what humanity would like to achieve, not just what it fears.

Dr. Vali agreed and specified that the speakers were not saying that all efforts for human exploration should be stopped, but that we should do it taking into account all necessary precautions.

Dr. Jasentuliyana suggested that the fact of participating in this workshop demonstrated that the participants were indeed eager to go forward but were also aware that any human intervention to nature must be done rightly and cautiously.