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MARS SAMPLE RETURN: A NEED FOR REVISIONS TO CURRENT POLICY TO SAFEGUARD ECOLOGICAL DIVERSITY

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ABSTRACT

Prior to deploying bi-directional probes that will return to Earth samples from the atmosphere, surface and subsurface of Mars, it is essential to fully appreciate the risks and impacts of possible biocontamination to planetary ecosystems on both Earth and Mars. NASA's present planetary protection policy (PPP) stems from: "Biological Contamination of Mars: Issues and Recommendations", the recommendations of the NRC's Space Studies Board, and is a weak and outdated policy that fails to adequately ensure protection of either Earth or Mars. This is due to the fact that this policy downplays the likelihood of finding life on Mars, discovering organisms that would also prove viable on Earth, and grossly underestimating the potential outcome of interactions between these seemingly disparate organisms and ecosystems. In light of mounting evidence which suggests the potential, past or present, for the existence of life on Mars – given by the suggestive results of ALH84001, a growing appreciation for the breadth of tenuous conditions under which extremophiles exist on Earth and, perhaps most importantly, the recent evidence from NASA suggesting the existence of liquid water near the surface of Mars – this paper calls for the implementation of a stricter PPP for the transfer and handling of samples derived from Mars. In contrast to NASA's present PPP, this paper argues that there are several significant ecosystems on Earth with the potential to be seriously impacted by the introduction of xenoterrestrial organisms. Thus, this platform aims to raise the awareness of the necessity to achieve a unilateral policy ensuring necessary care in handling samples returned from Mars by highlighting possible sources and routes of contamination to both planets and discussing methods for ensuring adequate segregation and evaluation of these samples, as well as the impact and management of a contaminating event.

INTRODUCTION

In exploring Mars we have progressed from telescopic viewing, to the deployment of unidirectional probes and have greatly advanced our understanding of the nature and history of Mars, the Solar system, planets, Earth, and the early history of life on Earth. Before we attain the pinnacle of planetary exploration by sending human missions to Mars, we must breach the next logical threshold by returning samples taken from the surface, subsurface, and atmosphere of Mars.

In returning samples from Mars we assume the risk of contaminating Mars with terrestrial

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microorganisms and also the chance of returning xenoterrestrial organisms to Earth. The inherent risk associated with both forms of contamination represent an issue that governments, space agencies, and private citizens should not take lightly. The purpose of this paper is to highlight the potential for finding life on Mars and to discuss ways in which the risks associated with these necessary Mars sample return missions can be mitigated.

PLANETARY PROTECTION POLICY [PPP]

Planetary protection describes the conservation of Earth and other bodies from exogenous forms of contamination (Race & Rummel, 1999; United Nations, 1967). Contamination can be *forward*, where outbound contaminated materials sent from Earth piggyback on a probe or other vehicle, or back (*reverse*) contamination where contaminated material is inadvertently returned to Earth.

There are countless scenarios where such contamination might occur. Of concern to most agencies is that forward contamination to Mars presents the risk of false positives in future tests for the history of life on the planet. There is some concern that in reverse contamination, xenoterrerestrial organisms or bioactive molecules might be returned to Earth, and possibly interfere with the biosphere of Earth (SSB, 1997).

BRIEF HISTORY OF PPP

For several decades it has been recognized that in studying space, and other planets, there is a need to protect Earth and other systems from inadvertent contamination arising from space exploration. To this end, a number of groups have attempted to negate this risk through primary prevention, namely identifying the sources of potential risk and taking action to ameliorate protocols. This is the central tenant of the Outer Space Treaty (United Nations, 1967) and the PPPs of the Committee on Space Research [COSPAR] (DeVincenzi, Stabekis & Barengoltz, 1996) and National Aeronautics and Space Administration [NASA] (NASA, 1999a). These groups operate at many levels, from the international (e.g., COSPAR, United Nations), to institutional (e.g., NASA). Common to these groups is a central theme related to the objectives of their PPP, and not surprisingly there is also lateral co-operation amongst the groups to allow updates and revisions to PPP to accommodate this perpetually evolving field of knowledge.

As the undisputed leader in space exploration, NASA has employed and refined PPP since the Mariner and Viking Missions, based on the early recommendations of COSPAR in the 1960s (DeVincenzi, Klein & Bagby, 1991). The present PPP at NASA — NPD 8020.7E (NASA, 1999a) — stems from the recommendations of the National Research Council [NRC]'s Space Studies Board [SSB] (SSB, 1997). Further, the SSB document has also been extended to guide the policy of COSPAR (DeVincenzi *et al.*, 1996). The SSB document represents an important step in actively attempting to obtain a balanced, multidisciplinary document toward inferring the nature of possible living entities on Mars and the risks and measures indicated by this risk. Unfortunately, relative to the exploration of Mars this document has been quickly superseded by new knowledge concerning the extremophiles, the frequent re-analysis of the asteroid ALH84001, and perhaps most importantly by recent evidence suggesting the presence of liquid water near the surface of Mars (Malin & Edgett, 2000).

Due to the view of PPP is a precautionary tool that aims to protect against hitherto unforeseen risks, it is possible at some level to understand why PPP is often overlooked, or at the very least downplayed. Possible instances that may result in PPP compromise include pressures resulting from social, time and financial constraints, as well as misunderstandings arising from the risks associated with future missions. As an increasing number of countries and private companies independently assume a greater role in space exploration, there is an obvious need for ubiquitous, clearly defined, and enforceable international guidelines to safeguard both Earth and other systems.

APPLICATION OF PPP

In developing their PPP, COSPAR has weighed the nature of the mission objectives against the risk of contamination (DeVincenzi & Stabekis, 1984; DeVincenzi *et al.*, 1996). For example, Category IV missions, applicable to the study of Mars, are subdivided into Categories IVa and IVb, where the latter represents the most stringent conditions, necessary for planetary landers containing life-detecting systems theoretically compromised by the presence of Earth-derived contaminants (DeVincenzi *et al.*, 1996). COSPAR recommends that for these missions the vehicle be sterilised to the levels of the Viking Lander missions of the 1970s, and assumes that inherent advances in the technology of sterilisation and microbial detection will result in lower levels of contamination. Category IVa levels denote pre-Viking levels of bioload reduction, thus lacking the final sterilising event.

Sterilising spacecraft and/or returned vesicles pose numerous difficulties: the harsh conditions diminishing the many types of micro-organism contaminants will invariably react with some of the many components of the space vehicle. It is probably best not to consider sterilisation in absolute terms, but rather as a procedure having a significant effect on reducing the bioload of the treated vehicle (NASA, 1999b). In this light, it is possible to see that for the most effective sterilisation it is necessary to employ a combination of currently available sterilisation techniques to reduce the overall bioload, maximising use of our current technology (Trofimov, Victorov & Ivanov, 1996). Obviously, in dealing with novel organisms whose lifestyles and weaknesses are unknown, these techniques may unwittingly prove ineffective. This should *not* result in outright grounds for dismissal of MSR projects, because it is virtually impossible to prove a negative hypothesis. Conditions for the sterilisation of the Viking lander mission, following clean-room assembly [class 100,000] and pre-sterilisation procedures [translating to a bioburden reduction to about 300 spores/m^2, with a total no more than $3.0x10^5$], included exposure to dry heat at 111.7C, 1.3mg/L humidity for 30 hours. Prolonged dry heat, while less effective than moist heat, has the added advantage of minimally interfering with sensitive equipment. However, other sporocidal methods of sterilising are also effective and merit mention. These techniques include: UV and ionising irradiation, which exert an effect by creating DNA cross-links, which interferes with DNA replication; liquid chemical solutions (e.g., ethanol/formaldehyde solutions) which cross the cell wall of bacteria to oxidise proteins; and some gases, such as ethylene oxide. For a review of these techniques and their limitations please refer to Trofimov *et al.* (1996).

Of course, it is much easier to evaluate and undertake sterilisation procedures on Earth. Yet to be established are the methods of sterilisation what will be carried-out on samples destined for return to Earth, and how the efficacy of that sterilisation will be assessed.

RECONSIDERING PPP

Lessons learned from extremophiles on Earth

Our awareness of the tenuous conditions under which organisms thrives here on Earth is continually increasing. Bacteria exist across extremes in pH, ranging from pH ~0 (*Picrophilus oshimae*) to over pH 11 (*Bacillus alcalophilus*). *Deinococcus radiodurans* and many bacterial endospores are able to withstand extreme amounts of ionising radiation. Micro-organisms thrive under extreme pressures found at the depths of oceans, and kilometres below the Earth's crust. Deep sea sulphide chimneys are home to hyperthermophilic bacteria that thrive at, or above, 115C; other species of bacteria can grow at temperatures as low as -20C (*Bacillus psychrophilus*). A report recently demonstrated a diversity of ecosystems below the surface of glaciers, suggesting an analogue to possible habitats on Mars (Skidmore, Foght & Sharp, 2000). Molecular phylogenetic data derived from 16S rRNA sequence homology comparisons has indicated that the oldest common relative on Earth is a hyperthermophilic bacteria that thrives at extremely high temperatures, suggesting a possible bottleneck effect in the evolution of micro-organisms on life.

The panspermia theory suggests that life arose on Earth via the introduction of life from elsewhere in the universe (Hoch & Losick, 1997). For example theories have suggested that life might have first arisen on Mars and then spread to Earth, or *vice versa* (Melosh, 1988); it has also been suggested that microbial life may have originated within comets, or evolved outside of our solar system and been seeded here by comets (Clark, Baker, Cheng *et al.*, 1999). Consequently, either of these hypotheses suggests that life would posses an inherent relatedness derived from this genetic bottleneck. Sterilizing impacts on Earth during the accretion period could also result in a similar phenomenon if all but the deep and protected hyperthermophiles survived such an event.

Experiments aimed at testing the limits of organisms under the conditions imposed by space may elucidate matters. Perhaps the most famous, albeit serendipitous, example of this occurred when a camera from Surveyor 3 contaminated with *Streptococcus mitis* was left for over two years in the cold, ionising vacuum of the lunar surface. The spores returned to Earth with Apollo 12 in 1969, where they were subsequently cultured. Another report claims to revive bacterial endospores of *Bacillus sphaericus* from amber samples over 25 million years old (Cano & Borucki, 1995).

By subjecting hearty organisms to the rigours of space flight by simulating the cold vacuum of space, radiation exposure, pseudocometary milieus, and the conditions at various regions of planets such as Mars, and Jupiter's moon Europa, it becomes possible to better appreciate the boundaries imposed upon living organisms. These studies offer insight into the potential for forward contamination, as well as information regarding the broad tolerance of varied environmental conditions by organisms. For example, Koike, Hori, Katahira *et al.* (1996) designed a series of experiments replicating various aspects of the conditions on Mars, the results suggest that terrestrial organisms could remain viable for extended periods of time on the planet. A related experiment examined the effects on bacterial spores, such as *Bacillus subtilis*, of long-term exposure to space (Horneck, 1993; Horneck, Buecker & Reitz, 1994), seemingly responding to the question posed in an earlier article: 'Can spores survive in interstellar space?' (Weber & Greenberg, 1985).

By pushing environmental extremes we gradually discover thriving ecosystems that are intimately tied to the larger biosphere. Extremophiles, bacteria that thrive in exceptionally harsh conditions, are the closest models that we have to what life putatively resembles in harsh xenoterrestrial ecosystems. However, it is not advisable to extrapolate from these organisms in order to derive conclusions about what life must resemble in conditions away from Earth. By examining these ecosystems and simulating, under laboratory conditions, the difficult environments thought to exist in space and on other planets, we gain a greater appreciation for the conditions under which life might exist and insight into how to test for related ecosystems away from Earth. This information indicates an appreciation for the risks of biocontamination stemming from forward contamination.

ALH84001

There is a growing body of literature describing the interpretations of the Mars meteorite ALH84001. Brief mention within this paper of the evidence surrounding the argument for past life in ALH84001 cannot do justice to the weighty arguments both for and against the validity of this assertion (Harvey & McSween, 1996; Jull, Courtney, Jeffrey *et al.*, 1998; Frankel & Buseck, 2000). However, it is important not to overlook or dismiss this information, despite growing criticism, in this developing field of research that has yet to be fully refined. The meteorite, recovered from Antarctica, has been dated to about 4.5 billion years age [bya] and is claimed to support biological hallmarks of past life from the subsurface of Mars dating 3.9 bya (McKay, Gibson & Thomas-Keprta, 1996). While no single piece of evidence unequivocally confirms the historical existence of life in the sample, the authors assert that the combined interpretation of several observations points to a common denominator (Gibson, Mckay, Thomas-Keprta *et al.*, 1997). Basically, the authors claim that there are carbonate globules within the meteorite similar to those produced by micro-organisms on Earth; additionally, these globules are associated with other mineral signatures of life, such as iron oxide and iron sulphide, which equilibrium would naturally deter. The presence of polycyclic aromatic hydrocarbons [PAHs], which are produced by the breakdown of organic matter, are also been touted as chemical evidence of past life on Mars. Using electron microscopy, the authors also claim structures within the carbonate resemble fossilised bacteria. These suggestions have been criticised for a number of reasons. A significant flaw appears to be that the authors did not appreciably consider nonliving sources of carbonate globules and PAHs as plausible causes of the observed phenomenon, particularly those that could arise in the course of the meteorite's travels from Mars to Earth. Furthermore the size of the fossilised structures, the smallest of which is 20nm wide, is significantly smaller than the lowest limits of 200-300nm imposed by predictions of metabolic constraints (reviewed in SSB, 1999a). Most recently evidence involving the deposition of magnetite, a characteristic deposit of some micro-organisms, has been used by the NASA group to maintain that the samples did, in fact, once harbour living organisms from Mars. Again, non-biological sources giving rise to this observation cannot be absolutely ruled-out.

The assertion that ALH84001 proves past life on Mars remains contentious, but this argument cannot be immediately disproved, either. Given the age and source of the meteorite, and an appreciation for the rigorous bombardment experienced by the planets at this time, it would be convenient to make the leap between this conclusion, and the rapid appearance of life on Earth. However, the fact remains that the inherent difficulties associated with studying fossilised bacteria and samples subjected to the rigours of time, ejection/impact, space, and exposure to micro-organisms on earth, it would not be surprising if a definitive conclusion was unattainable without tremendous advances in technology and exploration that could address the many questions raised by alternative suggestions regarding the cause of the properties described in ALH84001.

The implications of a recent presence of liquid water near the surface of Mars on the search for life

According to the SSB (1997): "*If active volcanism, or near surface liquid water, is discovered on Mars . . . the occurrence of extant life on the planet becomes more plausible*". Recently it was discovered that Mars harbours evidence of liquid water near the planet's surface (Malin & Edgett, 2000). The rationale behind the SSB's somewhat restrained statement is simple "*. . . terrestrial investigations of extreme environments now indicate that primitive life appears wherever liquid water and energy are present. . .*" (SSB, 1997).

Assuming that life on Mars bears some resemblance to life on Earth. It might be logical to expect that regions on Mars containing liquid water have a higher probability of containing viable organisms than harsher regions of the planet (NASA, 1995). While this hypothesis might be reasonable in the context of the panspermia paradigm, the origination of life *de novo* might not be presumed to lead to such a finding, unless there is an inherent force of nature that purposefully directs life into a particular pattern (e.g., the chirality of many biomolecules).

Since the Viking mission failed to demonstrate life on the surface of Mars, the planet has been increasingly viewed as merely a sterile planet that in the past may have once hosted life. As an aside, it is worth mentioning that one of the primary researchers working on the Labelled Release [LR] life-detection experiments for the Viking missions, Dr. G. Levin, maintains that the positive results obtained from the LR experiments were valid, and not attributable to inorganic reactions, as proposed by NASA (Levin & Straat, 1979). By confirming the presence of liquid water near the surface of Mars, hopefully the planet will be increasing viewed as potentially boasting a wealth of ecosystems.

As exciting as the potential for liquid water may be to the support of life on Mars, it is important not to downplay the possibility of detecting life in other promising regions of the planet as well. In fact, these areas also require particular emphasis in the planning of sample-return missions. Some include sites of volcanic and hydrothermal activity (NASA, 1995; SSB, 1997), the planet subsurface, and regions of low oxidation with temperature and humidity ranges consistent with that of some extremophilic organisms on Earth. Frozen areas, as well as the poles of the planet should not be abandoned as lifeless, nor devoid of frozen micro-organisms (NASA, 1995), since it is well documented that microbial life thrives in the water and surface of the admittedly less severe environments of the poles of Earth (Skidmore, Foght & Sharp, 2000; Priscu, Fritsen, Adams, *et al.*, 1998). As inhospitable as the oxidising surface of the planet may appear, it has often been suggested that this does not mean that micro-organisms cannot exist in water pockets within surface rocks. Additionally, the physical constrains of the surface could theoretically result in colonisation by organisms metabolically different from those in the experiments posed by the Viking missions.

The presence of liquid water below the surface of Mars also suggests the possibility that the water pools may be interconnected as they are on Earth. If so, it becomes necessary to consider the possible impact of accidentally contaminating a pool with terrestrial organisms, thereby permitting rapid spread of the contamination regionally, and perhaps globally. This analogy is akin to wind distributing organisms across the planet surface. This possibility is in direct contrast to an earlier suggestion of the SSB (1999b); hopefully, insight raised by the possibility of liquid water on Mars will be reflected by a change in the SSB's position.

RECOMMENDATIONS FOR MARS SAMPLE RETURNS [MSR]s

It would be imprudent to assume that any given region of Mars is devoid of life, although it is certainly true that many regions boast an increased likelihood of containing organisms. Given this assumption, it is clear that the current standards for PPP fall short of adequately protecting Mars from Earth-derived organisms. Further uncertainty related to the methods and policies designed to protect against reverse contamination also requires action.

Forward contamination

It is clear that our current PPP fails to adequately protect Mars from contamination with terrestrial organisms. By underestimating the likelihood of finding life on Mars, it is inevitable that our PPP will fail to take the most appropriate precautions, based on our current level of understanding of this matter and technological abilities, to protect indigenous organisms on Mars. By using only pre-Viking levels of bioload-reduction on landers to Mars, especially to regions hosting environmental conditions similar to that inhabited by terrestrial organisms on Earth, there is a more than reasonable risk of contaminating ecosystems. The Mars Climate Orbiter exemplifies this risk, as this probe crashed into the planet. Additionally, the possibility of introducing currently allowable levels of ‘hardy [heat resistant] organisms’ (NASA, 1999b) to these environments would seem irresponsible without better researching the efficacy of multiple sterilisation treatments on these organisms. Therefore, in the case of Mars it would seem prudent to treat all missions involving controlled landings on the planet at Category IVb levels, since there remains a risk to putative endogenous organisms, and not just the validity of life-detecting experiments for our benefit. Furthermore, according to the recommendations of COSPAR, probes orbiting Mars are required to meet only Category III levels of treatment, assuming that they fall below a certain level of risk for impacting the planet. If such a level of treatment were employed with the Mars Climate Orbiter it would appear that a region of the planet might have been unnecessarily exposed to levels of terrestrial organisms deemed excessive by our current standard level of understanding about the planet.

Reverse contamination

The SSB (1997) states: “. . . *each returned* [from Mars] *sample should be assumed to contain viable exogenous biological entities until proven otherwise*.” PPP for sample returns are still relatively lagging, and in light of the fact that NASA plans such a mission to Mars in 2005 (NASA, 1996), this is an area which needs to be rectified quickly (Race, 1998). Foremost, it is important to establish a set of criteria for treating all of the exposed surfaces of a vehicle, or capsule, to minimise the chance of contaminating any ecosystems on Earth. This of course, should be as strict as reasonably possible, but it is not inconceivable that it could be relaxed, following initial evidence that a region or environment is devoid of life. On the other hand, regions which have an increased likelihood of supporting life (SSB, 1997) should see an increase in the stringency of sterilisation procedures.

There are a multitude of ways that these differences can be handled using the categories outlined below. First, the type and combinations of sterilising techniques should be varied. Therefore, it is imperative that research be conducted into the most efficient and effective ways of sterilising probes, outside of the boundaries of Earth. This might include heat sterilisation (dry/moist), radiation (UV, and or ionising), chemical (liquid and gas), or a combination of the above. It is also important to explore the possibility of more specific, albeit more experimental, techniques such as lipases, proteases, and nuclease treatments. Ideally, enzymes could be targeted at cell membranes, or, more importantly, the nucleic acids of the organisms. This assumes that potential micro-organisms derived from Mars have, for example, nucleic acids coding their vital functions. While it is possible to see how these techniques might be applied to a sample-containingcapsule, the problem of a large vehicle is far more complex. Ideally, the smallest possible surface area is be recommended in returning a sample to Earth, so it may not be incomprehensible to suggest that a vessel/capsule containing the sample material be separated from a larger return vehicle, before reaching Earth.

Clearly, there are many ways in which to bring the sample to the planet surface, and it would seem important to host a forum to allow for the discussion of all possible solutions, drawing on the expertise of a multidisciplinary committee composed of: engineers, planetary scientists, biologists (biochemists, microbiologists, and ecologists), chemists, ethicists, lawyers and public representatives. Before proceeding to invest the resources, and to incur the risk of a MSR mission, it is advisable to at least attempt a volley of life-detection missions to the planet. This is true because such an attempt has not been made since Viking; the information that stands to be gained from *in situ* mission is enormous. With ensuing sample return missions, it would be ideal to pre-screen of a small portion of the sample *in situ*, or *en route* to Earth to advise if extra caution must be paid to the sample. This could also tell us if the mission need be aborted if the capsule seal has failed. Of course, in receiving the MSR, the notion of a remote lab on a far-removed body such as our moon, to prevent contamination of Earth is totally unreasonable. However, an orbiting lab, such as that of the International Space Station [ISS] might serve as an ideal platform for allowing an initial pre-screening of samples, using simple techniques that look, for example, for signs of metabolism or nucleic acids (SSB, 1997). Obviously, the sample canister can be designed such that the entire sample need not be opened and exposed, thus only a small fraction of the valuable cargo need incur the risk of contamination in the ISS lab, which would unquestionably be ill equipped compared to the Level 4 labs needed to properly handle the material initially returned to Earth. This would only be possible if it could be assured that the ISS could offer adequate sample containment and isolation; unfortunately, the added cost and equipment might be perceived as a barrier to this proposal. Other suggestions have included that the return capsule be brought into Earth orbit, and recovered by a subsequent space shuttle mission; however, the complex logistics and added equipment to the proposed capsule may prevent such a plan.

While it is neither ideal nor recommended, samples brought directly to the surface of Earth would have to be stringently handled to prevent exposure to environments conducive to the potential organisms carried in the samples. Here, for example, common sense would dictate that samples retrieved from the poles of Mars would not be returned, or risk contact with, polar regions of this planet; similarly, samples containing liquid water would not come in contact with lakes or oceans. It is possible to quickly see how difficult it would be to accommodate this important prerequisite. Additionally, because material can be brought through the Earth's atmosphere from space and not reach sterilisation temperature suggests that directly dropping a MSR capsule on Earth may efficiently inoculate Earth with samples of soil and gas from Mars, in the event of failure of the capsule's integrity. Because the proposed MSR set to launch in 2005 (NASA, 1996) involves the use of a free-falling return capsule, the possibility exists for contamination pending failure of the capsule's integrity.

To reflect the differences in the probability of finding micro-organisms associated with disparate sample locations (NASA, 1995), and to accommodate the inherent costs and technical obstacles of MSRs, it is proposed that the COSPAR Category V be sub-divided to reflect these differences in perceived risks. Areas considered low risk would include sites, or closely related physical environments, which have previously been demonstrated—by *in situ* life detection experiments, or sample returns—to not show signs of life, in environments predicted as likely habitats for organisms; for example, the inside of surface rocks. Sites of low probability for retrieving viable organisms, based on terrestrial profiles, but still meriting concern for the potential of organisms with characteristics different from those which we currently understand, the Category

Vb should be applied; for example, initial exposure to a harsh surface environment. Finally, for novel sites with a high probability of containing organisms, based on exaggerated terrestrial profiles and sites known to contain organisms, past or present, then the Category Vc would apply. To assign and discuss how the varied sample return procedures, such as sterilisation techniques, mode of sample delivery etc, will be handled, it is necessary again to draw upon the resources of the multidisciplinary committee as outlined above.

Another factor, which often appears overlooked with respect to MSR is the risk of virus contamination. By definition, viruses are not considered living entities, but their impact on living organisms is unquestionable. While it may be that there is less probability of accidentally unleashing a virus that has the potential to directly harm eukaryotes, the same may not be true of bacteria. If there are micro-organisms on Mars, then one must assume that there must also be bacteriophages. Medically, bacteriophages have promise as effective tools for killing bacteria (Alisky, Iczkowski, Rapoport *et al.*, 1998). If accidentally released, phages have the potential to specifically target populations of bacteria on Earth. Because of the pleiotrophic nature of phages, these viruses can demonstrate wide host ranges, and thus may demonstrate a high specificity in the bacterial population they target. Unlike many micro-organisms, viruses are obligate parasites. In their inactive state, some types of viruses are highly stable for long periods of time outside of the host organism. When frozen there is evidence suggesting that they can exist for extremely long periods of time in material such as ancient ice, on Earth. Consequently, even if the temperature ranges for polar ice in areas like our Moon, and more importantly Mars, are not presumed to harbour living organisms, a real concern should exist for the possibility that these regions contain viable viruses.

The consequences of eliminating or displacing large segments of bacterial populations, on Earth, regardless of the nature of the ecosystem, are unfathomable. All food pyramids ultimately rest on bacteria and globally the role of bacteria in our environments is grossly underestimated (Pace, 1997) and often poorly understood. The SSB (1997) concluded that putative micro-organisms from Mars are unlikely to pose a significant ecological risk to Earth, however, based on the aforementioned argument, it is possible to see that such a conclusion cannot be taken lightly. The literature abounds with examples of instances where outside competition resulted in the displacement of a species. For example, humans have contributed to the removal of many species from the planet; the introduction of many species of European birds to North America have displaced many traditional species of songbirds; bacteria colonising the gastrointestinal tract of humans are frequently displaced by foreign strains of bacteria and bacterial products (e.g., *Clostridium botulinum*); and scientists are currently exploring the use of bacteriophages to remove bacterial infestations from humans.

PPP and the public

Implicit to democracy is the opportunity for the public to become involved at all levels of activity that contribute to the workings of a country. While it is probably safe to assume that the general public is scientifically illiterate to the point it lacks the background necessary to come to independent decisions regarding the conduct of MSR missions, they do have the right to contribute to these discussions in a meaningful way. By excluding the public from being made acutely aware of the implications of this research, as well a the potential risks involved, a void is created, which gives an unbalanced voice in the favour of the media, conspiracists, and sources of erroneous information. It is imperative that the opportunity for public participation and input not only be included in the planning of a MSR (DeVincenzi & Klein, 1989; Race, 1995; Race, 1996; Race, 1998), but that it be actively encouraged, and that information—both technical and lay-friendly—be readily accessible, and that genuine concerns raised by the public be respectfully addressed.

There appears to be a sentiment among scientists that the public is a threat to the advancement of valuable research (Race, 1995). While this is true in some areas of research, the field of space exploration and sample return missions is particularly contentious, perhaps due to the use of controversial fuels, the great public expense, the potential for biocontamination, and the implications of research findings on religious and moral tenets. New media, in particular the Internet, have given the public the opportunity to receive and transmit information at a pace never before encountered. However, this levelling effect of the Internet, whereby a virtually equal weight is given to material published on subjects of all sorts, without peer review, makes it possible for erroneous and biased views to be similarly distributed. For this reason, there is a greater need for researchers and scientific agencies and government to effectively communicate their ideas and results and to present it in a manner that is digestible, but not insulting, to the lay public. It is also important that agencies demonstrate to the public a concern and accountability for their decisions, and to provide within reason, an opportunity to offer meaningful input. NASA has a "*. . . broad and unchallenged authority over a wide spectrum of activities related to "the successful use of outer space* [National Aeronautics and Space Act, 1958]" (Race, 1998) which conceivably may result in a perception of secrecy by the public. When denied access to official information and in the face of a poor understanding of the goals of an agency, it is not surprising if the public is more willing to accept alternative sources of information, potentially leading to actions that are not in the best interest of the agency or the public. The issue is further complicated by the fact that NASA, and related agencies, generally lack independent evaluation and testing, thus lacking the appearance of accountability.

IMPLICATIONS OF LIFE ON MARS

The implications of finding life on Mars are widespread. Clearly, it is critical that samples be evaluated and re-evaluated to initially rule-out the possibility of contamination or false positives, and to ensure that sufficient effort is made to understand the breadth and characteristics of the organisms, especially relative to their impact on ecosystems on Earth, and vice versa. This could be accomplished through developing standardised bioassays. Obviously, as on Earth, it is preposterous to assume that it could ever be possible to fully categorise and study the permutations of every known and viable organism on Mars. For this reason alone, the detection of life on Mars can not preclude the use of the planet for future exploration, human missions, or perhaps even colonisation. Obviously, it is necessary to be highly sensitive of the ethical implications of each of these suggestions; similarly, it would be naive and irresponsible for our civilisation not to broaden, to a reasonable extent, its understanding of the universe, or solar system, and the origins of life.

The discovery of life on Mars, in itself, would have widespread implications concerning the uniqueness of Earth and our biased attitudes regarding the special conditions that supported the origination of life here on Earth. If Mars hosted organisms with the appearance of containing a similar convergence of metabolic and genetic systems (Dyson, 1999) this would support an increased understanding for the range and prerequisites of the components constituting life. While such an observation could not rule-out convergent origin of life *de novo* on both planets, that is similar environmental pressures leading to similar metabolic and genetic adaptations/origins, the presence of molecular similarities in the structure and sequence of DNA/RNA base pairs and coding of amino acids would strongly suggest a relatedness to organisms on Earth. This, of course, is true only once the possibility of forward contamination has been ruled-out. This discovery could be interpreted as offering strong support to arguments for panspermia. This would, of course, pose a frustrating problem in analysing these samples, because the natural interpretation of this finding would be to an experimental error from contamination by terrestrial organisms. Incidentally, were this hypothesis true, one might also question whether remnants of ancient samples from seeding comets, or space debris/ejectae, might not persist in preserved pockets of space. For example, the cold poles of Mars, or perhaps the poles of the moon, which are believed to contain cometary ice in craters shaded from the effects of the sun.

DNA sequencing [particularly 16S rRNA] can be effectively used to extrapolate the relatedness of organisms (Woese, 1990). By determining the extent of evolution of the organisms, in the event that they are genetically DNA-based, it may be possible to infer whether life first arose on Mars, Earth, or concurrently on both planets. It is not the intent of this paper to describe the shortcomings of theories explaining the origination of life *de novo* on Earth; however, several hypothesis relate the relatively fast appearance of life following the end of the accretion period 3.8 billion years ago and the lack of evidence suggesting a means of generating life *de novo* (Sleep, Zahnle, Kasting *et al.*, 1989; Davis & McKay, 1996). It is clear that the discovery of, and research into, the possibility of life on Mars would be of unquestionable benefit to humankind.

SUMMARY

In light of recent evidence supporting an increased likelihood for our ability to detect life — past or present — on Mars, it is necessary to modify our present PPP to reflect our current level of scientific understanding surrounding this risk. With regard to both forward and reverse contamination, modification of PPP is necessary to better reflect the risks associated with encountering ecosystems on Mars, particularly polar, hydrothermal and aqueous environments. Given that a strong potential exists for transferring terrestrial organisms to viable ecosystems on Mars, it is recommended that all lander missions be categorized at the stricter COSPAR Category IVb, rather than IVa, level of sterilization until this and related landing sites can reliably be deemed devoid of life. Further, due to the risk– as illustrated by the recent demise of the Mars Climate Orbiter– it would be more responsible to reassign all Mars orbiters to Category Iva levels. Clearly, it will be important to re-evaluate the risks associated with MSRs to develop plans for retrieving, transporting, and isolating samples, before deeming the contents innocuous. It is also proposed that COSPAR Category V be subdivided to reflect differences in handling procedures (yet to be established) for samples taken from areas of varying risk: Va. Sites, or sites of closely related areas, which have previously been shown to be devoid of life. Vb. Sites of low probability of retrieving viable organisms, based on terrestrial profiles, but still meriting concern. Vc. Sites known to contain organisms, past or present; novel sites with a high probability of containing organisms, based on terrestrial profiles. Finally, it is suggested that agencies contributing to space exploration– particularly those related to MSRs– give the public an informed update on projects, and the opportunity to contribute input through participation in multi-disciplinary committees regarding mission planning.

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