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FINAL TECHNICAL REPORT
FOR NASA COOPERATIVE AGREEMENT NCC 2-706

INTEGRATION OF PLANETARY PROTECTION ACTIVITIES

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Submitted by

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Period of Performance

January 1, 1991 to April 30, 1995

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FORWARD:

This document is being submitted as a final technical report for research conducted under NASA Cooperative Agreement NCC 2-706 through the SETI Institute from January 1, 1991 to April 30, 1995. However, for reasons described below, the document represents more of an administrative final report than an actual final technical report for the research in question.

Based on recommendations of NASA internal reviewers in winter 1994-95, it was determined that this research project would more appropriately be categorized as a grant rather than a cooperative agreement. Accordingly, a changeover was made in 1995, terminating the cooperative agreement and initiating a new research grant under which the research would continue. The research accomplished under Cooperative Agreement NCC 2-706 actually took place in several distinct phases as follows:

January 1, 1991 to December 31, 1993:
Original 3-year research proposal renewed in Years 02 & 03.

January 1, 1994 to December 31, 1994:
3-year Continuation Proposal - approved for Year 01 only.

January 1, 1995 to April 30, 1995.:
No cost extension to cooperative agreement

May 1, 1995 onward: Starting date for new research grant.

While the cooperative agreement was formally terminated as of April 30, 1995, much of the research has continued as originally planned. Since May 1, 1995, the research work has continued under NASA Research Grant Number NAS 2-986 through the SETI Institute and NASA Ames Research Center.

FINAL TECHNICAL REPORT
FOR NASA COOPERATIVE AGREEMENT NCC 2-706

INTEGRATION OF PLANETARY PROTECTION ACTIVITIES

by
Dr. Margaret S. Race
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BACKGROUND:

For decades, NASA has been concerned about the protection of planets and other solar system bodies from biological contamination. Its policies regarding biological contamination control for outbound and inbound planetary spacecraft have evolved to focus on three important areas: 1) the preservation of celestial objects and the space environment, 2) protection of Earth from extraterrestrial hazards, and 3) ensuring the integrity of its scientific investigations. Over the years as new information has been obtained from planetary exploration and research, planetary protection parameters and policies have been modified accordingly. The overall focus of research under this cooperative agreement has been to provide information about non-scientific and societal factors related to planetary protection and use it in the planning and implementation phases of future Mars sample return missions.

In the face of its proposed series of missions to Mars, and in light of continued scientific interest in the possible existence of life on Mars, NASA has recognized the need to intensify its focus on planetary protection (PP) activities and requirements. It is apparent that planetary protection must include more than just scientific and technical aspects of the mission. It is generally acknowledged that before an official set of requirements can be established for a sample return mission, a variety of technical, legal and political issues and public concerns must be evaluated. Included among these are (1) evaluation of public concerns about returning samples from Mars into Earth's environment; (2) legal considerations and responsibilities of regulatory agencies; (3) analysis of the likelihood of an indigenous biota on Mars; (4) effect of Martian oxidants on terrestrial life; (5) technology for aseptic transfer of sample canister to Earth return vehicles; (6) technology for exterior sterilization of sample return vehicle; and (7) sample sealing and preservation technology to prevent movement of material in either direction. Because contamination control procedures can complicate mission design, are technologically challenging, and can have substantial impact on mission costs, answers to these and other planetary protection questions are needed in the near future for incorporation into all aspects of mission planning.

PROGRESS AND ACCOMPLISHMENTS: 1991-93.

The research conducted under this cooperative agreement sought answers to questions about planetary protection for future Mars exploration missions focusing on both forward and back contamination concerns. Like most projects, the objectives of the multi-year research evolved over time. Initially the objectives were stated in general terms because little information was available to judge the importance of societal and non-scientific factors as planetary protection concerns on future Mars missions. The general objectives for the first three years (1991-93) of the project were twofold:

1) to identify and analyze the efforts needed to inform, enlist and deal with the many audiences, clientele and public groups likely to require information on planetary protection prior to, during and after future Mars missions, and

2) to develop a comprehensive planning framework that could be used to manage and oversee PP activities and information flow associated with Mars missions.

The first year's work emphasized the gathering and analysis of information about NASA's planetary protection activities, both past and present, to determine the implications for proposed Mars missions, both with and without sample return. The work began with a comprehensive literature review on planetary protection and related topics (legal, historical, scientific, policy, risk communication, technical/engineering, management and institutional) in order to identify and evaluate key planetary protection issues and questions needing further research or attention by NASA.

The second and third years of research sought to gain a detailed understanding of societal and non-scientific factors representing potentially significant impediments for future Mars missions, and the relative importance of these factors on forward vs. back contamination concerns. The research also focused on understanding the nature of the external environment and public decision making arena likely to face future Mars sample return missions. A detailed comparison was made between sample return missions and scientific controversies involving public decision making in order to identify and more fully understand key areas or issues that may need special attention.

The ultimate goal of the 1991-93 research was to develop for NASA a comprehensive plan for planetary protection activities that would help guide the generation and flow of information required by various clientele groups and audiences. The work was driven by the belief that NASA must be selectively proactive in its handling of planetary protection research and concerns if it hopes to minimize disruption or delay to future Mars exploration missions, especially those involving sample returns to Earth.

During the period of the 1991-93 cooperative agreement, numerous presentations were made to NASA and the space community, to university academics, and to the general public, including:

Workshop on Planetary Protection Issues for the MESUR Mission: Probability of Growth (Pg), Palo Alto, CA, June 1991

National Academy of Sciences, Space Studies Board, Planetary Protection Workshop, Irvine, CA, September,1991

Energy and Resource Graduate Group Seminar Series, University of California at Berkeley, April 1992

Joint US/Russia Workshop on Planetary Protection Implementation for Future Mars Lander Missions,Palo Alto CA, July 1992

University of California Alumni Association, Invited Speaker, August, 1992

World Space Congress/COSPAR, Washington D.C.,September, 1992

University of California Alumni Association, Invited Speaker, Los Angeles, March 1993

NASA Ames Research Center, Space Science Division Seminar Series, April 1993

Two papers were written and submitted for publication during the 1991-93 grant period. (listed below with their ultimate publication dates and citation information):

Race, M.S. Mars Sample Return and Biohazards: A Source of Public Concern and Controversy. In *Case for Mars V*, edited by P. Boston, American Astronautical Society, Univelt Press, San Diego. (currently in press--- anticipated publication date: 1996)

Race, M.S. Societal Issues as Mars Mission Impediments: Planetary Protection and Contamination Concerns. Adv. in Space Research, vol. 15 (3): pp 285-292, 1995.

PROGRESS AND ACCOMPLISHMENTS: 1994-95

Based on insight gained in the first phase of this research, refinements in research emphasis were made to focus subsequently on four particular non-scientific and societal areas because of their importance to future mission planning and concerns about critical timing or possible economic impacts on mission implementation. The priority areas identified in the 1994-96 continuation proposal included:

1) questions of legal uncertainty and the decision making process,

2) public perception of risks associated with sample return,

3) planetary protection implications of alternative mission architectures-- both robotic and human sample return missions, and

4) risk communication via the mass media .

Because of the early termination of the cooperative agreement to change to grant status, only 1.3 years of work were accomplished towards these objectives (through April 30, 1995). As mentioned above, work continues to the present on these objectives under NASA Research Grant # NAS 2-986.

During 1994-95 under this cooperative agreement, research was conducted on the following three areas:

1. Legal Uncertainty and Decision Making Process

• Conducted a survey of domestic laws and regulations as well as international treaties to determine their applicability to various sample return proposals and their likelihood of presenting problems for the decision making process and implementation of mission plans.

• Outlined the entire decision making process associated with sample return missions, identifying clientele groups needing information at different times, key perspectives and interests represented by various groups, and probable situations or issues in which concerns about risks could prompt legal challenges, public opposition or intense media focus. This phase included an assessment of intra-NASA and organizational issues that could impact the decision making process leading to Mars sample return missions.

2. Risk Perception

• Began theoretical development and conceptual work to investigate the public's understanding and perceptions about the risks of sample return in order to provide information ultimately needed for planning, preparation, and delivery of a comprehensive risk communication program for Mars missions.

3. Mission Architecture :

• Began analysis of proposed mission architectures for both robotic and human sample return missions to assess strengths and weakness from legal, management, social and operational perspectives as they relate to planetary protection concerns. Special emphasis was focused on potentially problematic steps or situations arising from planetary protection concerns that could impact mission success such as environmental impact statement requirements, operations of quarantine facilities and methods of transporting samples after arrival on Earth.

The goal of this second phase of the research was to assist NASA in eventually formulating an effective risk communication strategy that is responsive to specific informational needs of various clientele and audience groups and that effectively anticipates potential opposition and challenges to sample return missions based on planetary protection concerns.

During the period of the 1994-95 cooperative agreement, formal presentations on research progress were made at various conferences and meetings including:

Conference on the Media and Environmental Risk. Association for Education in Journalism and Mass Communication. Reno, Nevada. April 1994.

Fifth Exobiology Symposium and Mars Workshop, NASA Ames Research Center, April, 1994.

Invited Workshop on Invasion Biology, Genetic Resources Conservation Program, UC Davis, May 1994.

Mars Exobiology Strategy Workshop, NASA Ames Research Center, July 1994.

30th COSPAR Scientific Assembly, Planetary Protection for Solar System Exploration. Hamburg, Germany, July 1994.

One paper was written and published during the 1994-95 period:

Race, M.S. Anticipating the Reaction: Public Concern About Sample Return Missions. Planetary Report, Volume XIV(4) pp.20-22. July/August 1994.

In addition, extensive technical assistance about planetary protection and Mars missions was provided to subcontractor Dr. Paul Slovic, who was collaborating under this cooperative agreement on research related to risk perceptions about sample return. This collaboration led to two additional publications under this cooperative agreement during 1994-95:

MacGregor D.G., and P.Slovic. Planetary Exploration Survey. Planetary Report, Volume XIV(4) pp.20 (2 page insert). July/August 1994.

MacGregor D.G., and P.Slovic. The Planetary Exploration Survey: What Society Members Think About Planetary Protection. Planetary Report, Volume XV(2) pp.4-6, March/April 1995.

Ultimately, this line of research on risk perception will be helpful in assessing how the public perceives sample return, providing information that will help evaluate the effectiveness of different risk communication strategies for various audiences. In addition, the results will be helpful in anticipating social concerns and possible legal challenges based on public concerns about sample return.

APPENDICES:

A. BUDGETS:

During the span of this cooperative agreement, annual budgets were as follows:

Year 01	January 1, 1991 - December 31, 1991.	$ 67,000
Year 02	January 1, 1992 - December 31, 1992	$ 59,767
Year 03	January 1, 1993 - December 31, 1993	$ 63,356
Year 04	January 1, 1994 - December 31, 1994	$ 70,384
	January 1, 1995 - April 30, 1995	No cost Extension
	TOTAL COSTS:	$260,507

B. PUBLICATIONS AND ABSTRACTS

Publications:

M.S. Race. Mars Sample Return and Biohazards: A Source of Public Concern and Controversy. In *Case for Mars V*, edited by P. Boston, American Astronautical Society, Univelt Press, San Diego. (currently in press---anticipated publication date: 1996)

M.S. Race. Societal Issues as Mars Mission Impediments: Planetary Protection and Contamination Concerns. Adv. in Space Research, vol. 15 (3): pp 285-292, 1995.

M.S. Race. Anticipating the Reaction: Public Concern About Sample Return Missions. Planetary Report, Volume XIV(4) pp.20-22. July/August 1994.

D.G. MacGregor and P.Slovic. Planetary Exploration Survey. Planetary Report, Volume XIV(4) pp.20 (2 page insert). July/August 1994.

D.G. MacGregor and P.Slovic. The Planetary Exploration Survey: What Society Members Think About Planetary Protection. Planetary Report, Volume XV(2) pp.4-6, March/April 1995.

Abstracts:

M.S. Race. Societal Issues as Mission Impediments: Planetary Protection and Contamination Concerns. The World Space Congress/COSPAR, Washington D.C., 1992.

M.S. Race. Implications of Legal Uncertainties, Public Perceptions and the Decision Making Process for Mars Sample Return Missions. Fifth Exobiology Symposium and Mars Workshop, NASA Ames Research Center, 1994.

M.S. Race. Planetary Protection, Legal Uncertainty and the Decision Making Process fo Mars Sample Return. 30th COSPAR Scientific Assembly, Hamburg, Germany, 1994.

MARS SAMPLE RETURN AND BIOHAZARDS: A Source of Public Concern and Controversy

Margaret S. Race*

Societal concerns about environment, health, and safety are likely to complicate planning for future Mars missions, especially those involving sample returns. Unless planners and engineers seriously consider "biohazard" and "planetary protection" concerns during the earliest mission planning stages, it's possible that public opposition, cost increases and missed launch windows will interfere with mission success. Using lessons learned from genetic engineering and past environmental controversies, it's possible to understand and anticipate how social and non-scientific factors could adversely impact future missions to Mars. In the face of important social trends of the past two decades and the public's growing aversion to perceived risks and biohazards, NASA should adopt a strategy that actively plans both the generation and subsequent management of planetary protection information to ensure that key audiences obtain needed information at appropriate pre-launch times.

INTRODUCTION

Mars is a prime target in the continuing exploration of the solar system for clues concerning the origin, evolution and distribution of life and life-related molecules.[1] Much of the interest and focus of Mars missions has been centered around the search for life and the eventual return of samples from the planet. As scientists plan future missions, they currently entertain three alternative views about life on Mars. Most scientists familiar with Viking results believe that the existence of life on present-day Mars is improbable anywhere on the planet, although it cannot be ruled out with certainty. Some scientists believe there is a remote possibility that if a living system did arise on Mars during its more benign past, it may have been able to adapt to deteriorating conditions as the planet lost most of its atmosphere, cooled down and dried out— and that living organisms may still be present on Mars in suitable, as yet unidentified niches.

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Finally, some suggest that if life evolved on Mars but died out as the planet deteriorated, it may be possible to detect these ancient extinct organisms in future sampling. Because it is impossible to determine with certainty which of these views accurately reflects the situation on Mars, both the space community and the general public are likely to remain interested in the outcome of future Mars exploration and the search for life.[2] Accordingly, it is imperative that mission planning efforts seriously address concerns about planetary protection and biohazards to prevent harmful cross-contamination of planets during space exploration.

Concerns about planetary protection and biohazards are hardly new. NASA has taken planetary protection concerns seriously for decades, with its attention focused largely on hardware and technical aspects of planetary protection controls[3] NASA's current planetary protection policy (NMI 8020.7C, December 12, 1991) requires:

> "The conduct of scientific investigation 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. Therefore, for certain space-mission/target-planet combinations, controls on organic and biological contamination carried by spacecraft shall be imposed..." [4]

In planning for future missions there is a need to recognize that a variety of social and non-scientific factors also have important implications for planetary protection. Over the past two decades, social and non-scientific issues have played increasingly important roles in the outcome of conflicts over technological decisions and actions involving government agencies, industry, and the public. Because the decision to return a sample from Mars has environmental, health and safety concerns, it will be subject to intense scrutiny by both by the space community and the general public, with much of the debate occurring in the public realm. To prepare for this scrutiny, those involved with Mars missions must be aware of how social and non-scientific factors relate to planetary protection. By drawing on lessons learned from genetic engineering and past environmental controversies, it is possible to anticipate how social and non-scientific issues could adversely impact future Mars sample return missions. As a generalization, delay or avoidance in dealing with these social and non-scientific issues early in mission planning will greatly increase the likelihood of public opposition, cost increases and missed launch windows for future Mars sample return missions.

PLANETARY PROTECTION

In practical terms, concerns about planetary protection focus on two key areas: *forward contamination*, the introduction onto a planetary body of terrestrial microbes carried on outbound spacecraft or equipment; and *back* *contamination*, the introduction onto Earth of contamination or life forms carried in return soils or samples. Two distinct perspectives underlie concerns about contamination: one emphasizing *protection of the planets* based on concerns about ecological principles and public/planetary health, and the other emphasizing *protection of experiments* based on concerns about the conduct of scientific investigations and mission success. For forward contamination, the two perspectives translate into concerns about (1) the potential for growth of terrestrial organisms on Mars and (2) the importation of terrestrial organic contaminants, living or dead, in amounts sufficient to compromise the search for evidence of past or present life on Mars itself.[2] For back contamination, the concerns are (1) the potential for survival and growth of martian organisms on Earth, and (2) unintentional contamination of martian samples with earth organisms in ways that might compromise scientific their interpretation.

Protection of planets is of interest to both the space community and the general public, and is backed by explicit and implicit legal requirements that apply to space activities (e.g., the Outer Space Treaty; domestic and international laws governing environment, health and safety). In contrast, protection of scientific experiments is of interest mainly to space scientists and managers, and is backed by legally non-enforceable management directives and policies promulgated by space agencies. Over the years, planetary protection requirements used by NASA have aimed to satisfy both perspectives simultaneously, despite the possibility that implementation for one may or may not completely satisfy the other. Both perspectives clearly have implications for Mars missions, although protection of planets, especially Earth, is likely to carry more weight in mission planning and implementation because of public concerns.

PAST EXPERIENCES WITH PLANETARY CONTROL

Forward Contamination

Over the years, discussions about forward contamination controls for Mars missions have focused on the extremely low probability of growth of terrestrial organisms in the harsh martian environment and the question of whether Viking-like controls would be unnecessarily stringent and costly to future outbound missions.[5] A 1992 report by the National Academy of Sciences, Space Science Board unanimously concluded that forward contamination is *not* a significant hazard to the martian environment if Viking-type controls are used, but could be a problem for future *in situ* experiments specifically designed to search for evidence of extant or fossil martian organisms.[2] The NAS recommendations for forward contamination controls distinguished between missions with and without life detection experiments because of lingering concerns about protection of experiments. They recommended that " landers carrying instrumentation for *in situ* investigation of extant martian life should be subject to at least Viking-level sterilization controls...", while "...spacecraft (including orbiters) without biological experiments should be subject to at least Viking-level presterilization procedures-- such as clean-room assembly and cleaning of all components-- for bioload reduction, but such spacecraft need not be sterilized." In general, public concerns about forward contamination have been minor, with little or no negative impact on missions to date.

Back Contamination

Despite previous experiences with sample return and back contamination controls during the Apollo Program, planning for Mars sample return is essentially in the conceptual stage. While much of the knowledge and experience from handling lunar samples will be helpful in mission planning, it cannot prepare NASA and its mission planners completely for a Mars sample return for a number of reasons. Major engineering and scientific questions must be answered before the public can be reassured that back contamination controls are effective and adequate. Numerous technical and engineering problems remain to be solved including: design of the sample return canister with effective sealing and preservation to maintain the sample at Mars ambient conditions; how to break surface contact with Mars and accomplish sterile insertion of the sample; development of a fail-safe system for monitoring the sample and canister during the long return flight; methods and equipment for recovering, handling and transferring the sample upon landing; design, location, construction and operation of quarantine facilities; and development of appropriate equipment and barriers for sample handling, testing and storage.[6] Scientific research will also be needed to answer questions about Earth-based sampling and testing, especially those related to operational protocols for the quarantine facilities, testing methods and experimental protocols for samples, development of appropriate bioassays, and curation and control of samples.

It will also be necessary to overcome the organizational and management problems that contributed to inadequate protection against back contamination during the Apollo Program. As discussed by Bagby [7] and Mahoney[8], these included overt resistence to procedures by flight personnel, challenges to authority by non-NASA personnel, diminished attention to quarantine procedures in favor of other mission priorities, unfamiliarty of scientists with operational procedures at the quarantine facility, inadequate decontamination of laboratory personnel, and intraorganizational conflicts.

Finally, in addition to the technical, scientific, management and organizational issues facing mission planners, issues of back contamination have serious societal, legal and international implications. As noted by DeVincenzi et al [1] even when all the technical questions are answered, recommendations about planetary protections based purely on technical considerations may eventually play a secondary role in developing the final strategy for contamination controls, especially for back contamination

IMPORTANT NON-SCIENTIFIC AND SOCIAL FACTORS

In the two decades since Apollo sample returns, significant changes have occurred in American public policy, with corresponding impacts on how the public and experts are involved in decision making [9]. Numerous examples can be found of scientific and technical projects that were frustrated by public challenges and concerns. Retrospective analyses of these diverse controversies have led to an understanding of how various factors contribute to project opposition in the public realm. Particular trends that have important implications for planning Mars sample returns include 1) a dramatically different external setting, 2) institutionalized public opposition and vigilance, 3) gradual, but significant shifts in the nature of public decision making, and 4) an increasingly risk averse public and mass media.[10] Each of these is discussed briefly below.

1) *Dramatically different external setting:* Major changes in laws and gover nment institutions have occurred over the past two decades that encourage increased public participation in the decision making process while imposing complex new regulations about health, environment and safety. NASA will be less able than in the past to make unilateral decisions about many critical aspects of sample return missions including quarantine, transportation, monitoring, environmental effects, and health concerns.

2. *Institutionalized public vigilance and opposition*: Public vigilance and opposition are now essentially institutionalized both domestically and internationally in the form of well-funded, highly organized, non-governmental watchdog groups that monitor government actions, lobby political allies, conduct independent analyses, participate in regulatory and oversight processes, challenge government and corporate actions in court , and communicate with the public through the mass media. NASA already has faced costly legal challenges of the Galileo and Ulysses launches based on RTG's, nuclear materials in space, and possible launch accidents. Opponents of Mars missions could use a variety of laws (e.g., the National Environmental Policy Act (NEPA) and its impact statement requirements) in their attempts to stop sample returns.

3. *A gradual but significant shift in the nature of public decision making*: Instead of being dominated by risk analyses and one way communication from experts, the decision making process is now highly political, with expectations of a two way dialogue involving government agencies, experts and the public. Debates about risk no longer focus exclusively on quantitative factors, but regularly include unmeasurable qualitative concerns and value judgements. Miscommunication can occur between experts and the public when different levels of a controversy are intermixed. Typically, one can find three distinct levels in a controversy: an ideological or public policy focus dominated by

philosophical questions of "should we do it"; a procedural focus, dominated by questions of "how should we do it"; and a local focus, dominated by questions of "why do it here or now?" In extremely complicated situations, all three levels can be involved simultaneously, mixing large societal questions and local opposition with the experts' task of assessing and managing the risks in a practical sense. Historically, NASA engineers and managers have been accustomed to reaching decisions through a highly technical process with only minimal input from the public. However, decisions about planetary protection will undoubtedly impose a heavy load of social concerns onto mission planning, shifting the emphasis for decision making into a more public realm where it may be complicated by multiple perspectives.

4. *An increasingly risk averse public and mass media*: Research has shown that the general public has become more risk averse over time, and that it perceives and judges risks differently than experts. In general, people allow certain qualitative factors (i.e., involuntariness, dread, unfamiliarity, mistrust in institutions) to disproportionately influence their perceptions of risk more than technical quantitative features. These facts, combined with the general decrease in scientific literacy among the public, suggest that discussions about planetary protection and sample return may be complicated by fear, lack of understanding and an anti-technology bias. In addition, the public's selective concern with danger is powerfully shaped by the media, whose coverage of potentially hazardous events is governed more by a need to excite the public than to inform it .[11]

Although gleaned from mostly American examples, these trends should not be viewed as uniquely American phenomena or responses. For example, Europe is experiencing a growth in both professional and public interest in the character and management of risks despite the fact that the public is less informed about their responsibilities, choices and legal options.[12] Even in the emerging democracies, people are questioning government actions that could impact their health and environment. It's possible that international concerns, either alone or in combination with American opposition could challenge future sample returns. For example, in the Galileo launch, legal challenges in American courts were filed by an American group as intervener for German Green Party members who sought to protect their lands and people from potential environmental disasters similar to Chernobyl.

COMPARISON WITH GENETIC ENGINEERING

While it's impossible to predict how technical, engineering, management, operational, legal and social factors may combine to effect a particular mission or launch, it is possible to understand the planetary protection concerns of a mission by scrutinizing a situation with remarkable similarities. Such an example can be found in the "Ice Minus" controversy, an outdoor experiment in the mid-1980's involving the first intentional release of an organism created by genetic engineering with recombinant DNA technology. Published reviews provide a detailed historical analysis of events during the controversy as well as a lengthy discussion of the differences between scientific and public perceptions of the experiment.[13]

Briefly, the project involved a small-scale field test of genetically engineered bacteria by university researchers to determine their effectiveness in preventing frost damage to agricultural plants. Opponents succeeded in delaying the experiment for five years through a succession of legal challenges and public policy maneuvers that kept the debate in the public spotlight. They characterized the proposed experiment as reckless because it used a truly "exotic" organism which, they claimed, had the potential to cause untold environmental problems if released. The controversy ultimately involved federal, state and local government agencies; legislative bodies and the courts; public hearings and environmental impact documents; and intense media coverage. A comparative analysis between ice minus and Mars sample return is useful to identify potential areas of public concern. Important similarities and differences between the two cases can be seen in three general areas: 1) the nature of the organisms and experimental conditions, 2) characteristics and concerns of accident scenarios, and 3) the institutional and legal framework for each situation.

Similar to the ice minus experiment with its novel, genetically engineered microbes, a sample return mission will involve the possibility of handling new, "exotic" life forms not found on Earth (Table 1). Both experiments involve the intentional handling and importation of a novel life form (as opposed to an accidental encounter), and scientists in government agencies were/are assigned the task of determining appropriate controls for monitoring the experiment. The ice minus experiment was propelled by questions of basic scientific interest with only indirect long term benefits to society in the form of possible frost protection for crops. A sample return mission will be based on the most basic of scientific questions related to the origin of life in the universe, and can claim no direct or indirect societal benefits except the generation of new knowledge. Another feature in common with ice minus is the division of expert opinion. Already, credible scientists are divided on whether life exists on Mars or would pose a risk to terrestrial organisms. Unfortunately, unlike the ice minus experiment which had elaborate pre-testing under quarantined conditions, it will be difficult or impossible to conduct extensive pre-testing or experiments with organisms from Mars. Finally, like the ice minus experiment, Mars sample return is constrained by a specific time "window" during which conditions are suitable. Public controversy or indecision about permits for sample return missions could translate into extensive time delays and added costs, a serious problem considering the short duration of launch windows (in weeks) and the multi-year span between suitable launch windows. Like ice minus, the scientists' practical concerns about making quick decisions to proceed with the experiment could be misinterpreted as forcing a questionable decision on an unwilling public.

Both ice minus and Mars sample return are similar in their accident scenarios and public perceptions (Table 2). Like ice minus whose opponents focused on worst case scenarios with drastic environmental and safety effects, a proposal to import Martian life is likely to face opponents' claims of dreaded or catastrophic consequences, uncontrollability, irreversibility, possible global impacts and effects on future generations. In the event of active public opposition, intense media attention can be expected, with the coverage ranging from accurate information to mild analogy to sensationalism bordering on science fiction. In the ice minus experiment the public was concerned about the wide range of risks it faced, from impacts on environment and health to possible consumer crop boycotts. The sentiment was voiced that such large risks far outweighed the comparative benefit of merely increasing scientific knowledge without any intended applications. With sample return, the public may question the inequitable distribution of risks and benefits, with the space community seen as reaping the potential benefits from a successful experiment, and the general or local population incurring the health and environmental risks should an accident occur. Opponents can raise ethical questions as well, noting that it is morally wrong to interfere with the evolution of life, whether by genetic engineering or on another planet. In addition, for both ice minus and Mars sample return, potential accidents are seen as completely avoidable because they are caused by deliberate human action rather than "acts of God." Using this reasoning, some argue that the best way to avoid a problem is not to undertake the experiment at all. Many of these claims and concerns are difficult or impossible to address factually in the decision making process through environmental impact statements and permit documents.

Finally, for both ice minus and Mars sample return, areas of legal and institutional ambiguity abound (Table 3). The initial legal challenges against ice minus came in part from assertions that NIH guidelines for handling genetically engineered organisms were not legally enforceable regulations. Current and past planetary protection controls are likewise based on legally non-enforceable guidelines promulgated by COSPAR. The ice minus experiment remained in the public spotlight intermittently for several years until areas of legal uncertainty were resolved through legislative and public hearings, agency deliberations and in the courts. Among the key legal issues were questions of which agency or agencies had ultimate control and authority for issuing permits for genetic engineering, and whether new or existing environmental laws and regulations should be applied for this new area of experimentation. Additional complexity was added by conflicting jurisdictional questions at federal, state and local levels covering topics ranging from environmental impact statement requirements to transportation permits, quarantine controls, neighborhood zoning and experimental monitoring. For Mars sample return mission, lawyers have pointed out that legal obstacles could arise from uncertainty about control and authority, international treaty obligations, and constitutional concerns about quarantine, public health and safety.[14, 15] Other legal requirements may also arise under various domestic regulatory laws, but details will vary depending on the specific mission profile.

The controversy over ice minus and genetic engineering caused the establishment of the Biotechnology Science Coordinating Committee, a federal interagency group to debate and resolve complex questions. For the Apollo Program, decisions about back contamination controls, quarantine protocols and quarantine facilities were handled by an Interagency Committee on Back Contamination (ICBC). Because there is no modern day counterpart to ICBC, future establishment of an interagency body may be needed to handle questions about sample return and planetary protection controls, especially in the face of today's more complex environmental, health and safety laws. As was seen in the ice minus experiment, citizens' involvement is almost assured for sample return because of the openness of current government decision making processes. In addition, both domestic and international environmental groups and public advocacy organizations can make use of American laws to challenge proposed scientific/technical actions. International groups such as the United Nations, the World Health Organization, and the International Labor Organization have also attempted to address questions involving protection of Earth's environment and minimizaion of risk to populations from space exploration activity.[2] Even if Russia or some other nation undertakes a sample return, many of the same questions and challenges could be raised, as citizens worldwide have become more vigilant about questioning proposed government actions with potential environmental and health consequences.

CONCLUSION

Despite the preponderance of similarities between the ice minus experiment and Mars sample return, there is one important way in which they are very different. Throughout the public debate about ice minus and genetic engineering, the university and its researchers were entirely reactive, proceeding one step at a time in response to public challenges, legal action or agency requests for information. There was essentially no institutional advance planning on how to proceed through the decision making and permit process. The experiment was scientifically and legally a test case, with little precedent to guide it. In contrast, those involved in future sample return missions can be proactive in many ways. Assuming at least a decade before a sample return mission would occur, it is possible to identify key planetary protection areas needing special research and planning, much in the way that advance development is done for mission hardware and technology.

Typically, in the early phases of any mission planning, NASA has almost complete internal control over questions and how it chooses to handle them. On most projects, there is a tendency to concentrate first on the hardware, technology, mission architecture and costs, leaving environmental values and non-scientific aspects in the background, to be dealt with at a later stage in a way that minimizes added project costs. However, relegating the study of social, environmental and non-scientific factors to a later stage of planning is ill advised for a controversial Mars sample return mission and may, in the long run, be more costly in many ways. According to NASA's internal NEPA guidelines[16], "consideration of the possible environmental effects of any NASA actions must be included at the earliest stages of study and planning, just as are technical and economic factors. Decisions -- or recommendations for decisions-- must be made with as full a knowledge and understanding of the likely environmental effects as is possible..." In addition, Presidential Directive NSC-25 requires Presidential review and approval for "experiments which by their nature could reasonably be expected to result in domestic or foreign allegations that they might have major and protracted effects on the physical or biological environment or other areas of public or private interest..."[17] Once the public becomes aware of the behind-the-scences decision making about a sample return mission and its possible risks, subsequent discussions could easily shift into the public realm, over which NASA has far less control.

Without serious, proactive and early attention to questions of legal uncertainty, mission architecture, human vs. robotic sample return, risk assessments, risk perceptions, management problems, quarantine planning, public communication, and media response, NASA may find itself inadequately prepared to deal with public questions. Not only would planning for the mission be complicated, but NASA might face major delays, increased costs and even missed launch windows as it responded in a totally reactive mode to legal and public demands for more analysis or information. Considering the striking similarities with the ice minus experiment, such proactive research and planning would be prudent to anticipate problem areas and minimize the chances of social and non-scientific factors becoming major mission impediments. Delay or avoidance in dealing with the social and non-scientific factors is indefensible, either legally, practically or ethically.[2,18] If NASA and other space agencies are seriously committed to future Mars sample return missions, it is important to acknowledge from the start the degree to which social and non-scientific factors could complicate missions in unpredictable ways.

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Table 1

COMPARISON OF ORGANISM AND EXPERIMENTAL CONDITIONS

ICE MINUS	MARS SAMPLE RETURN
Novel life form created by genetic engineering. **Lack of public understanding about "mutant" organisms** and recombinant DNA technology.	**Truly "exotic" life form** from another planet. **Lack of public understanding about nature of life on Mars** and the debate over extant vs. extinct life forms.
First intentional release of a genetically engineered organism into an open air environment	**First intentional importation** and handling of extraterrestrial sample since lunar samples.
Reason for experiment was to test scientific hypotheses about microbial frost protection and ecological competition. No anticipated applications or products from the experiment. **No immediate public benefit.**	**Reason for sample return based on scientific hypotheses** about the evolution of life in the cosmos. No anticipated applications and **no immediate public benefit** besides knowledge.
Site specific design & tight controls on experimental conditions imposed by government regulators to minimize human exposure and/or spread of organism beyond test plot.	Mission design will incorporate **strict planetary protection controls.** Likely to have many environmental, health and safety requirements imposed for general sample handling and site specific quarantine.
During pre-experiment debate, **experts were divided on level and types of risks posed by experiment.** The majority of mainstream scientists felt the experiment was low risk from scientific, environmental and public health standpoints.	**Experts currently divided on views about life on Mars.** Most believe that life on present-day Mars is improbable and would not pose a threat to Earth's environment. Details about sample handling and testing must still be worked out.
Extensive background information was available from pretests with actual recombinant organism under contained greenhouse conditions. Good data on non-pathogenicity of test organism to animals, humans and plants.	**Impossible or very difficult to pretest martian samples prior to sample return** to develop extensive background information on organisms(s). Depending on the success of robotic precursor mission(s), may have limited data on pathogenicity or other characteristics of martian life prior to sample return.
Experiment faced the constraint of a "biological window", with suitable experimental conditions found primarily in early spring (& a secondary "window" in early fall.) Each delay in making permit decisions resulted in putting the experiment off by an entire growing season. In the end, multiple challenges led to five years of delay.	**Missions to Mars face tight "launch windows"**, based on planetary alignment and launch preparation requirements. Legal challenges or delays in obtaining necessary permits could caused missed launch windows with costly delays.

Table 2

ACCIDENT SCENARIO AND PUBLIC PERCEPTIONS

ICE MINUS	MARS SAMPLE RETURN
Public concerns focused on worst case scenario (changing global weather patterns, uncontrolled "escape" of microbe to natural environment). **Public perceptions were shaped by concern over dreaded outcomes, involuntary exposure and uneven risks vs. benefits.**	**Environmental Impact Statement requires articulation of worst case scenario**, which the public is likely to focus on (e.g.,breach of quarantine facilities, escape of organisms, explosions, human error, "accidents"). **Public perceptions likely to be shaped by dreaded risks & involuntary exposure.**
Media coverage included focus on fear and sensationalism, at times bordering on science fiction (mutant potatoes, "germs", dreaded global disruption, loss of crops and economic livelihood)	**Likely media attention will cover factual information as well as controversy, perceptions and sensationalism** (Martians, Andromeda Strain, infectious agents, extraterrestrials, protests etc.).
Focusing on areas of scientific uncertainty and accident possibilities, **public questioned trustworthiness of decisions by scientists and bureaucrats**	Based on agency accident history and past failure to follow Apollo sample return protocols, **public may have reason to distrust NASA's ability to follow PP controls as planned.**
Many unquantifiables complicated decision making process (e.g. possibility of a consumer boycott, ethical and .ideological concerns about "playing God", uncertain environmental and health impacts of biotechnology; irreversibility, etc)	**Unquantifiables will be part of decision making process** (ex., moral issue of interfering with evolution of life on another planet; difficult to estimate risk probabilities with unknown organism; possibility of human error in handling and quarantine; etc.)

Table 3

INSTITUTIONAL & LEGAL FRAMEWORK

ICE MINUS	MARS SAMPLE RETURN
Initial permit request based on non-enforceable NIH guidelines and policies for recombinant DNA experiments	**Current planetary protection controls based on non-enforceable COSPAR guidelines** and space agency policies.
Represented a test case with **legal challenges based on major questions about agency authorities and responsibilities** (NIH vs. EPA vs. USDA as well as state and local jurisdictional concerns) and **uncertainty about appropriate laws** (toxics laws vs. pesticide laws vs. plant pathogen laws vs.proposed new biotechnology laws)	Many **current legal questions about agency authorities and responsibilities** (NASA vs. EPA vs. others agencies) and **uncertainty about appropriate laws** (NEPA, NASA authorizing legislation, quarantine and public health laws, transportation laws, etc). Possible other questions based on international treaties.
Experienced many and conflicting legal requirements (experimental permits, programmatic environmental impact statements, transportation permits, zoning ordinances, laboratory biosafety requirements, federal & state environmental impact statements)	**Likely to face many and conflicting legal requirements** (permits for quarantine facility , federal environmental impact statements for missions and sample returns, transportation permits from landing site, health and biosafety permits, presidential or national security review, etc.)
Legal questions and jurisdictional concerns led to **establishment of interagency biotech coordinating committee** and many legislative hearings	**May need to establish an interagency committee on back contamination** as seen during Apollo Program. Uncertain whether legislative hearings might needed.
Citizens advocacy group involvement allowed via NEPA and CEQA processes. **Intense media attention** of controversy and decision making process at national, state and local levels.	**Domestic and international opposition groups or individuals could challenge plans** for sample return using US laws. **Intense media coverage could be expected.**
University scientists and administrators were in a totally reactive mode for the duration of the controversy. No control over the length of time to resolve controversy in public arena.	**NASA administrators have opportunity to be proactive** before controversy erupts in public. Selective pre-planning and advanced research should help minimize impact of probable challenges from external sources.

BOOK OF ABSTRACTS

43rd Congress of the International Astronautical Federation • IAF

29th Plenary Meeting of the Committee on Space Research • COSPAR

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In summary, the infrared spectra indicate the presence of HMT having absorption features which should be visible in the middle infrared spectra of comets and interstellar ice grains, and the photochemistry of HMT under astronomical conditions may lead to the identification of the origin of the cyanide long observed in the tail of comets.

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F3.3-
M.1.08

LEGAL ASPECTS OF PLANETARY PROTECTION FOR MARS MISSIONS

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The planning and execution of manned and robotic missions to Mars present a wide range of jurisprudential issues. Provisions to prevent the disruption of natural celestial environments, as well as damage to the environment of Earth by the return of extraterrestrial materials, are important components of the law applicable to mankind's activities in outer space, and have been supplemented by scientifically instituted planetary protection policies. However, conflicting legal regimes may exist, as the space treaties in force are neither uniform in their provisions, nor identical as to the states which have signed, ratified, or adopted the international agreements. The legal requirements applicable to a specific mission will vary depending on the entities conducting the program and specific mission profile. This article analyzes the divergent international legal regimes together with the factors which will influence the determination of the standards of conduct which will govern manned and robotic missions to Mars.

F3.3-
M.1.09

SOCIETAL ISSUES AS MISSION IMPEDIMENTS: PLANETARY PROTECTION AND CONTAMINATION CONCERNS

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Societal and non-scientific factors represent potentially significant impediments for future Mars missions, especially in areas involving planetary protection. This study analyzes public concerns about forward contamination to Mars and back contamination to Earth and evaluates major areas where lack of information may lead to uncontrollable impacts on future missions. The study concludes that NASA should adopt a strategy that actively plans both the generation and subsequent management of planetary protection information to ensure that key audiences obtain needed information in a timely manner. Delay or avoidance in dealing with societal issues early in mission planning will increase the likelihood of public opposition, cost increases and missed launch windows. These findings also have implications for RTG launches, nuclear propulsion and other NASA activities perceived to have health, safety or environmental implications.

F3.4-
M.1.01

ORIGIN OF TITAN'S ATMOSPHERE

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The absence of abundant Ne on Titan indicates that the atmosphere must be secondary, a result of degassing and volatilization of the solid materials that accreted to form the satellite. This accretion could have involved materials from both the Saturnian subnebula and from the solar nebula itself. The destruction of CO in Titan's upper atmosphere together with the high value of D/H in Titan's methane suggest a primordial origin for Titan's CO and N_2. The presence of N_2, CO and CO_2 on Triton tends to reinforce this idea. Confirmation can come from detection of large amounts of solid CO_2 on the surface, or abundant, non-radiogenic argon in the atmosphere.

F3.4-
M.1.02

TITAN'S ATMOSPHERE COMPOSITION : CERTAINTIES AND SPECULATIONS

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Our knowledge of the atmospheric composition of Titan in 1980 has been drastically improved these last years from an indepth analysis of all data obtained during the encounter of Voyager with Titan and from subsequent ground based near infrared and millimeter observations. The nature of the surface of Titan, the existence of tropospheric methane clouds, the composition and distribution of aerosols and the degree of complexity of the organic chemistry occurring in the atmosphere of the satellite are still debatable. Are also controversial the temporal variability of the photochemistry, the pattern of the winds and the existence of a like-Venus superotation of the high atmosphere.

F3.4-
M.1.03

THE ORGANIC HAZE ON TITAN

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Titan's atmosphere is of interest to exobiology primarily because of the chemical conversion of the gases CH_4 and N_2 to solid organic material. Based upon laboratory studies and *Voyager* observations we have some understanding of the physical and optical properties of the Titan haze. However, our understanding of the gas to solid conversion process on Titan is incomplete. Key questions that remain concern the processes that occur in the size range too small to be considered by microphysical models and too large to be considered by photochemical models. Of particular interest should be the development of models that can explain the C/N ratio (~ 1) in the organic haze and the production rate (~ 10^{-11} kg m $^{-2}$ s^{-1}).

F3.4-
M.1.04

TITAN'S PHOTOCHEMICAL AEROSOLS

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The unsaturated compounds in Titan's atmosphere: C_2H_2, C_2H_4 and HCN polymerize photochemically, to form aerosol particles. The optical properties of the aerosols from each material and their agglomeration into non-spherical particles were studied in our laboratory. We are currently studying the properties of co-polymers, formed by irradiation of mixtures of C_2H_2, C_2H_4 and HCN together.

These aerosols are sticky even at -20°C and could coat the Huygens probe during its descent through Titan's atmosphere.

F3.4-
M.1.05

THE NATURE OF TITAN'S AEROSOLS: LABORATORY SIMULATIONS

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The atmosphere of Titan is known to contain aerosols, as evidenced by the Voyager observations of at least three haze layers. These

FIFTH SYMPOSIUM ON CHEMICAL EVOLUTION & THE ORIGIN AND EVOLUTION OF LIFE

and

THE WORKSHOP ON MARS EXOBIOLOGY SCIENCE STRATEGY

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IMPLICATIONS OF LEGAL UNCERTAINTIES, PUBLIC PERCEPTIONS, AND THE DECISION MAKING PROCESS FOR MARS SAMPLE RETURN MISSIONS

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In discussing implementation approaches for future Mars mission, it is important to acknowledge the public and legal context in which mission decision making will occur. When compared with similar public science controversies, such as genetic engineering, Mars sample return missions possess every element of the worst case scenario for social debate and controversy. As scientists, engineers, mission planners and administrators develop planetary protection requirements for future missions, they must be mindful of the many environment, health and safety concerns likely to surface for missions involving sample return to Earth. Changes in the legal and decision making environments since the time of Apollo sample returns have provided the public with many ways to challenge or delay missions and their launches. To the extent that planetary protection questions are unresolved at the time of an actual mission, they offer convenient footholds for public challenges in both legal and decision making realms, over which NASA will have little control.

Two particular areas in the social and non-scientific realms are especially ikely to complicate mission planning and implementation: 1) questions related to legal uncertainty and the decision making process and 2) public perception of risks associated with sample return. In combination they have a great potential to adversely effect future mission costs and timing. Particular legal questions that may cause problems include uncertainty about institutional control and authority over decision making; international treaty obligations; and constitutional and regulatory concerns about quarantine, public health and safety. Additionally, the public's perceptions of the risks and values of sample return could prove problematic, especially if adverse perceptions contribute to legal challenges. Understanding public perceptions will be critical to developing effective and appropriate information for various audiences concerned with sample returns. To minimize mission impediments, it is essential that NASA incorporate both legal and public considerations into the earliest planning phases so as to anticipate problem areas and prepare for legitimate public questions and challenges to sample return missions.

Public Concern About Sample Return Missions

by Margaret S. Race

Space scientists and engineers will plan missions to return samples from other worlds to Earth before they have answers to questions about the possibility of life on those worlds. We know Mars as well as, perhaps better than, any other extraterrestrial planet in our solar system, yet we cannot say for certain whether life ever existed there, or if it still does. Consequently, the spacefaring nations will continue to impose planetary protection controls on missions to avoid the risk of alien organisms contaminating Earth or terrestrial organisms invading other worlds.

Before official protection requirements are established for Mars sample return missions, we must consider a variety of social and political issues as these missions are planned. If ignored, these issues could become serious impediments.

When the *Apollo* astronauts returned to Earth with samples of the Moon, their mission planners faced a different, and in some ways more innocent, world. In the intervening years, public attitudes about technological hazards have shifted, causing public policies to change. Let's look at four particularly noteworthy shifts that have implications for sample return missions:

1. A dramatically different legal and regulatory environment. Laws and government institutions have changed to encourage public participation in the decision-making process. At the same time, imposing and complex new regulations about health, environment and safety have been instituted.

2. Institutionalized public vigilance. Today, public vigilance is maintained by well-funded, highly organized, nongovernmental watchdog groups. As we've seen with the challenges to launching *Galileo* and *Ulysses*, which carried plutonium power plants, opponents can scrutinize missions for perceived or actual environmental, health and safety risks. They can use a variety of legal avenues in attempts to stop a mission.

Mission planners will also have to consider the policies of international groups, such as the United Nations and the World Health Organization, which have addressed concerns about protecting Earth and minimizing risk to populations from space exploration activities.

3. Politicization of technological debates and shifts in the nature of public decision-making. Since *Apollo* times, there has been a gradual but significant shift in the nature of public decision-making, from unquestioning acceptance of closed-door, unilateral decisions by experts to the expectation of open communication among government agencies, experts and the public. If concerns about risk thrust technical discussions about planetary protection into the public realm, such discussions will be complicated by questions that are difficult or impossible to answer with scientific data.

4. A risk-averse public combined with mass media coverage focusing on hazards and disasters. The public is less willing to accept risk and more wary of technology, and expects experts to prove in advance that activities will pose no risk. Mass media coverage, which often focuses on potential accidents and disasters, powerfully shapes perceptions about risk. Sensationalized media coverage about planetary protection and sample return missions could intensify public anxiety.

While it's impossible to predict exactly how the public will respond to sample return proposals, it's advisable to anticipate complications. As people with demonstrated interest in planetary exploration, Planetary Society members will be among those who will weigh the benefits and the risks.

The Ice-Minus Experience

One way to anticipate problems is to scrutinize past controversies. A good case is the public debate over genetic engineering in the mid-1980s centering on a new organism created by recombinant DNA technology. Although it did not involve extraterrestrial organisms, this so-called ice-minus experiment illustrates the kinds of concerns and controversies possible for planetary sample return missions.

The ice-minus controversy involved the first intentional release of a genetically engineered organism into Earth's environment. A team of university researchers sought government permits for a small-scale field test of a mutant bacterium to determine the strain's effectiveness in preventing frost damage to agricultural plants. Opponents characterized the experiment as reckless because it used an organism not naturally found in the environment. They claimed it might cause drastic problems if released.

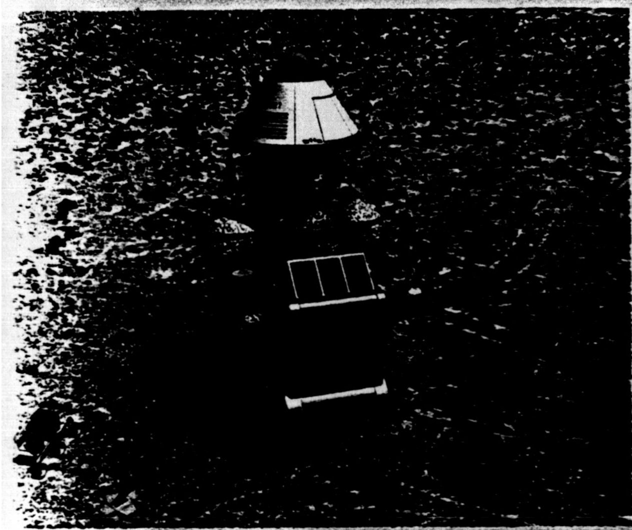
Through a succession of legal challenges and public policy maneuvers, opponents maintained a lengthy public debate over genetic engineering. By the time the experiment was done—without incident—nearly five years later, the controversy had involved federal, state and local government agencies; legislative bodies and the courts; public hearings and environmental impact documents; and intense media coverage.

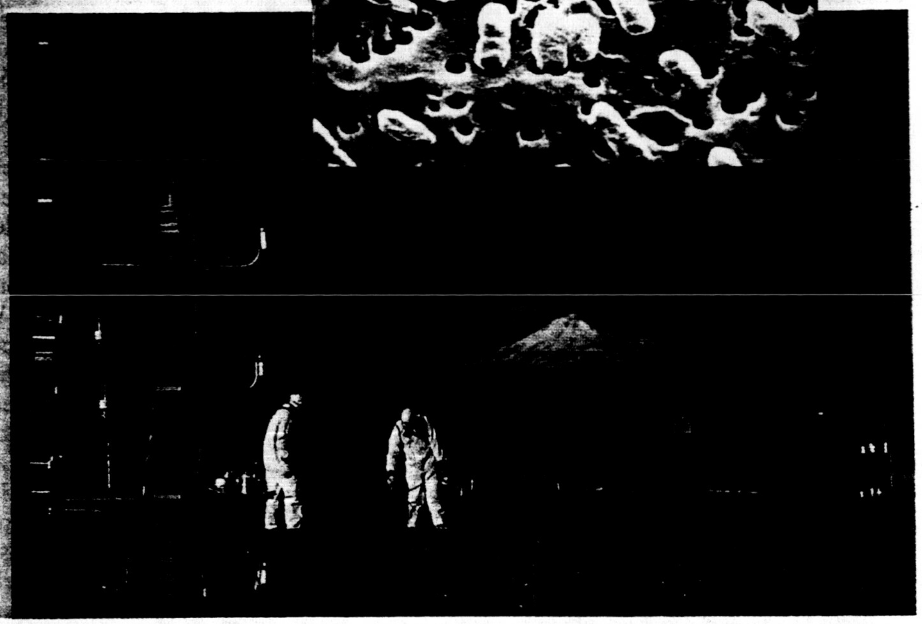
Let's examine some similarities to possible sample return scenarios, focusing on a Mars mission.

New Life-forms

Like the ice-minus experiment, a sample return mission could involve the deliberate handling and importation of new life-forms under experimental conditions.

The ice-minus experiment was spurred by basic scientific





ABOVE: NASA and other space agencies around the world are considering Mars sample return missions. The agencies know how to handle engineering designs and scientific experiments, but the possible public reaction to bringing pieces of another world back to Earth may be more difficult to address. This is a mock-up of a recent design. Illustration: NASA

TOP RIGHT: The ice-minus bacteria are seen in a scanning electron micrograph. Photograph: Kit Galvin, courtesy of Steven Lindow

RIGHT: The bacteria were first released outdoors at Tulelake, California, in May 1987. Scientists were required to wear protective garb, and the US Environmental Protection Agency set up meteorological equipment in towers to monitor the bacteria's dispersal. No adverse effects were detected. Photograph: Gary Anderson, courtesy of Steven Lindow

questions, with only indirect benefits to society in the form of frost protection for crops. A sample return mission will be based on scientific questions about the nature of the planets and life in the universe, with no predictable societal benefits except the generation of new knowledge.

Experts were divided in their opinions of the risks of the ice-minus organism, but the majority judged the experiment to be of low risk. Despite extensive testing under quarantine before the actual experiment, opponents remained unconvinced and continued to challenge it. Today, most scientists expect that martian soil samples are unlikely to contain life, although they continue to debate whether life exists on Mars or would pose a risk to terrestrial organisms. Even if Mars samples were handled under stringent quarantine, the public might still view the possibility of escape, however low, as a threat to the terrestrial biosphere.

Finally, the ice-minus experiment was constrained by a seasonal window. Mars sample return missions are limited by launch windows a few weeks long that occur only every two years. Legal challenges, public controversy or indecision could translate into delays and added costs. As with ice minus, scientists' practical concerns about reaching a decision to proceed could be misinterpreted as forcing a questionable decision on an unwilling public.

The Perception of Risk

The public may raise many concerns that are difficult or impossible to address factually. Proposals to import martian soil samples could face claims of dreaded or even catastrophic consequences, such as uncontrollability, irreversibility and global effects for present and future generations. As with ice minus, the public may question both the value of the benefits and a perceived inequitable distribution of risks and benefits. Space scientists and engineers could be seen as reaping the benefits, but the general or local population could incur the risks if an accident occurred.

Because of the complexity of the debate, it is questionable how well the mass media will convey information. Their coverage is likely to range from accurate information to mild analogy to sensationalism bordering on science fiction.

Who'll Call the Shots?

The initial legal challenges to ice minus came, in part, from assertions that guidelines for handling genetically engineered organisms were imposed by a federal organization that did not have the authority to either write or enforce regulations under existing laws. From the earliest days, planetary protection controls have been based on nonstatutory guidelines from COSPAR (the Committee on Space Research of the International Council of Scientific Unions), a nongovernmental organization concerned with cooperative international space research. The ice-minus experiment remained in the public spotlight for years until areas of legal uncertainty were resolved through legislative and public hearings, agency deliberations and the courts. For Mars sample returns, lawyers have already pointed out that legal obstacles could arise from uncertainty about control and authority, international treaty obligations, constitutional concerns about quarantine and environmental impacts.

During the *Apollo* program, a specially established Interagency Committee on Back Contamination (ICBC) handled the decisions about back-contamination controls, quarantine protocols and facilities. Similarly, the federal Interagency Biotechnology Science Coordinating Committee was established to resolve complex genetic engineering questions. It may be necessary to set up an interagency body to handle questions about planetary protection, especially in the face of today's more complex environmental, health and safety laws.

Typical Mission Profile for a Robotic Mars Sample Return

For Russia, the United States and the other spacefaring nations planning to explore Mars, a sample return mission is high on their agendas for early in the next century. These are the major features of a possible mission. This mission profile reflects current engineering designs and incorporates a set of constraints addressing planetary protection concerns.

- Two spacecraft, a Mars lander (subjected to *Viking*-like sterilizing treatment) and orbiter, are launched by a single rocket.
- The spacecraft fly to Mars (approximately nine months).
- Lander is targeted to predetermined site.
- Rover collects samples of rocks, soil and crust.
- Pure atmospheric samples are taken.
- All samples are stored in canisters under near-Mars conditions.
- Mars ascent vehicle with canisters launches into Mars orbit.
- Vehicle and orbiter rendezvous.
- Sample canisters are transferred to sterile vault on orbiter without contaminating the sample return capsule.
- Vault is sealed to provide biological containment.
- Orbiter fires engines to return to Earth.
- Sample return capsule separates and directly reenters the atmosphere.
- Capsule is retrieved by helicopter air snatch.
- Sample vault is opened under sterile conditions in a high-containment facility.
- Samples are tested for living organisms, biological hazards, and toxicity with a quarantine protocol.
- Samples are released for multidisciplinary analyses.

Recognizing the Right to Know

For a high-profile mission like a Mars sample return, the international space agencies will need to do everything in their power if they are to avoid criticism and ensure success. They must treat societal concerns about such missions seriously from the start.

In NASA, for example, there is a tendency to concentrate on hardware, technology and mission architecture, with nontechnical topics seen as undesired add-ons that complicate the mission and increase costs. For sample return missions, relegating social, environmental and nonscientific issues to a later stage of planning may ultimately prove more costly, both economically and otherwise.

With any sample return mission, the space agencies will face unavoidable legal requirements. For example, the international Outer Space Treaty requires that appropriate measures be taken to ensure that space activities are conducted to avoid harmful contamination of celestial bodies or adverse changes in Earth's environment.

In the United States, NASA has interpreted the National Environmental Policy Act as requiring "consideration of the possible environmental effects of any NASA actions at the earliest stages of study and planning" in order for recommendations and decisions to be made with full knowledge and understanding of the likely environmental effects. NASA will also have to respond to government regulatory agencies with authority over quarantine, environmental or safety areas.

Considering the quarantine problems during the *Apollo* missions and the recent failures of *Challenger*, the Hubble Space Telescope and *Mars Observer*, the regulatory agencies and the public may accept nothing short of comprehensive analysis and full disclosure as required by law. It is almost certain that NASA will face public challenges about sample return risks long before launch time.

For sample returns from space, the public concerns will undoubtedly be centered on back contamination. These same concerns are likely to generate the most media attention. Just as with the ice-minus experiment, scientists' explanations of technological design and their reassurances of exceedingly low risk will not deter people from challenging the mission.

Ultimately, it is for citizens to determine the types and degrees of risk they will accept. Thomas Jefferson wrote, "I know of no safe depository of the ultimate powers of the society but the people themselves, and if we think them not enlightened to exercise their control with a wholesome discretion, the remedy is not to take it from them, but to inform their discretion."

That is precisely what the space agencies of Earth must do during every phase of mission planning and sample return from other worlds.

Margaret S. Race is an environmental policy analyst and assistant dean in the College of Natural Resources at the University of California, Berkeley.

Planetary Exploration Survey

by Donald G. MacGregor and Paul Slovic

Your Opinion Counts

The opinions you as a member of The Planetary Society have about planetary exploration are important in formulating plans for future explorations of the planet Mars. We would very much appreciate it if you would take a few moments of your time to complete the following survey. When you are done, remove the survey from the magazine by tearing along the perforation, and fold it as indicated. The return address is already printed on the survey. A summary of the survey results will appear in a future issue of *The Planetary Report*. Thank you very much.

For each question, check one box.

What proportion of the articles in this issue of *The Planetary Report* have you read?

- ☐ All
- ☐ More than half
- ☐ Less than half
- ☐ None yet

Which of the following best describes how you feel about the **benefits of planetary exploration** compared to the **risks of interplanetary contamination?**

- ☐ BENEFITS GREATER than risks
- ☐ Benefits and risks EQUAL
- ☐ RISKS GREATER than benefits

Please indicate your level of agreement or disagreement with each of the following items by circling one response per item.

SD=Strongly Disagree; D=Disagree; A=Agree; SA=Strongly Agree; DK=Don't Know

Space exploration is essential to the future of our society.	SD	D	A	SA	DK
I am familiar with NASA's plans to conduct missions to the surface of Mars.	SD	D	A	SA	DK

Listed below are four categories of benefits to society that could result from planetary exploration. For each category, indicate how you feel about the benefits of planetary exploration by circling one response.

LB=Low Benefits; MB=Moderate Benefits; HB=High Benefits

Economic	LB	MB	HB
Scientific	LB	MB	HB
Military	LB	MB	HB
Human fulfillment	LB	MB	HB

Listed below are a number of hazards. For each hazard, please rate the risk for your country as a whole by circling one response.

AN=Almost No Health Risk; S=Slight; M=Moderate; H=High; DK=Don't Know

Radon	AN	S	M	H	DK
Genetically engineered bacteria	AN	S	M	H	DK
Ozone layer depletion	AN	S	M	H	DK
Satellite debris	AN	S	M	H	DK
Nuclear power plants	AN	S	M	H	DK
Biological contamination from Mars missions in the future	AN	S	M	H	DK
Bacteria in food	AN	S	M	H	DK
Electromagnetic fields	AN	S	M	H	DK
Asteroids	AN	S	M	H	DK
Global warming	AN	S	M	H	DK
Pesticides in food	AN	S	M	H	DK

Please indicate your level of agreement or disagreement with each of the following items by circling one response per item.

SD=Strongly Disagree; D=Disagree; A=Agree; SA=Strongly Agree; DK=Don't Know

Life, in some form, exists on other planets in our solar system.	SD	D	A	SA	DK
Intelligent life exists on other planets in the universe.	SD	D	A	SA	DK
If there is intelligent life on another planet, it poses no threat to us.	SD	D	A	SA	DK
Robotic space missions will tell us all we need to know about other planets.	SD	D	A	SA	DK
It is highly probable that life, in some form, exists on Mars.	SD	D	A	SA	DK
It is morally wrong to bring life back to Earth from another planet.	SD	D	A	SA	DK

SD=Strongly Disagree; D=Disagree; A=Agree; SA=Strongly Agree; DK=Don't Know

It is morally wrong to introduce life from Earth onto another planet.	SD	D	A	SA	DK
Humans on space missions should not directly contact the surface of other planets in our solar system.	SD	D	A	SA	DK
If there is *any* form of life on Mars, it should be left there undisturbed.	SD	D	A	SA	DK
Any mission that could expose Earth to life from Mars should be cancelled.	SD	D	A	SA	DK
If there is life on Mars, it poses no threat to life on our planet.	SD	D	A	SA	DK
Contamination of the martian environment by Earth life is not a significant hazard of planetary exploration.	SD	D	A	SA	DK

SD=Strongly Disagree; D=Disagree; A=Agree; SA=Strongly Agree; DK=Don't Know

An asteroid-detection system is essential to the security of Earth and its inhabitants.	SD	D	A	SA	DK
I would favor the development of defense systems to intercept and deflect asteroids that threaten Earth.	SD	D	A	SA	DK
No form of life presently on Earth can survive unprotected in space.	SD	D	A	SA	DK
If there is life on Mars, it most likely has adapted to that specific environment and would not survive here.	SD	D	A	SA	DK
If there is life on Mars, it has survived in such severe conditions that it would probably thrive on Earth.	SD	D	A	SA	DK
The environment on Mars is too harsh to sustain any life from Earth.	SD	D	A	SA	DK

SD=Strongly Disagree; D=Disagree; A=Agree; SA=Strongly Agree; DK=Don't Know

If Earth and Mars were contaminated millions of years ago by meteorites from each other, then there is no reason to be concerned about planetary protection today.	SD	D	A	SA	DK
All materials brought to Earth from Mars should be considered hazardous until proven otherwise.	SD	D	A	SA	DK
Life that has evolved in Earth's rich natural environment would not be fit enough to survive on Mars.	SD	D	A	SA	DK
Experiments done on Mars will be sufficient to determine whether it is safe to bring materials back to Earth.	SD	D	A	SA	DK
The benefits to society of the super-conducting supercollider would be worth its costs if it were built.	SD	D	A	SA	DK
The benefits to society of mapping the human genome are worth its costs.	SD	D	A	SA	DK
Intelligent extraterrestrial life will be discovered within a decade or so.	SD	D	A	SA	DK
We should prove that no life exists on Mars before sending humans there.	SD	D	A	SA	DK
More funds should be devoted to the search for extraterrestrial intelligence.	SD	D	A	SA	DK
Decisions about health and safety risks should be left to the experts.	SD	D	A	SA	DK
We should reduce or eliminate our reliance on animals in scientific research.	SD	D	A	SA	DK
All forms of nature have a right to be left undisturbed by humans.	SD	D	A	SA	DK
Nature can compensate for any harm that human activities might cause to it.	SD	D	A	SA	DK
I would greatly lower my standard of living if it would ensure nature is not harmed.	SD	D	A	SA	DK

(Please fold along dotted line.)

Please rate how much you trust NASA to accomplish each of the following by circling one response per item.

NT=No Trust; ST=Slight Trust; MT=Moderate Trust; HT=High Trust; DK=Don't Know

Successfully complete a Mars sample return mission	NT	ST	MT	HT	DK
Protect Mars from contamination by Earth organisms	NT	ST	MT	HT	DK
Protect Earth from contamination by Mars organisms	NT	ST	MT	HT	DK
Respect public values and opinions about the risks and benefits of space exploration	NT	ST	MT	HT	DK
Honestly inform the public about risks from planetary contamination	NT	ST	MT	HT	DK

Thank you for your participation!

[redacted]

Age: ____________

Sex: ☐ M ☐ F

Occupation: ______________________________

Country of residence: ☐ US (zip code): ____________

☐ Other (indicate): ____________

If you are affiliated with any environmental groups (e.g., Greenpeace, the Sierra Club), please list them here.

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The Planetary Exploration Survey:

What Society Members Think About Planetary Protection

by Donald MacGregor and Paul Slovic

4 There are hopes and plans to send many spacecraft to Mars' surface in the next decade, and each one will have to meet certain criteria to help ensure that it does not carry terrestrial invaders to the martian environment. Among the spacecraft could be the proposed Mars Polar Pathfinder. Painting: William K. Hartmann

The July/August 1994 special issue of *The Planetary Report* covered the topic of planetary protection, a matter that must be confronted as space scientists and engineers plan new missions to Mars and other planets in our solar system. We asked Society members to share their views on many aspects of the topic by completing a survey questionnaire included in that issue.

More than 4,300 Society members from countries around the world responded. That so many of you were willing to share your opinions with us was both gratifying and exciting. As we promised, here's a breakdown of members' responses to the survey.

Value of Space Exploration and Scientific Research

The vast majority (95%) felt that space exploration is essential to the future of our society, and most (85%) said they were familiar with NASA's plans to conduct missions to the surface of Mars. Not surprisingly, the majority saw space exploration as having high benefits in terms of scientific knowledge and human fulfillment; fewer people saw high benefits in economic and military areas (see Figure 1).

In general, Society members strongly supported other large-scale scientific research, and held highly positive views about the benefits of the superconducting supercollider, mapping the human genome and continuing the search for extraterrestrial intelligence (see Figure 2).

Potential for Life on Other Planets

The possibility of life on other planets is one of the most intriguing aspects of space exploration. While people who responded to the survey were either skeptical or uncertain that intelligent extraterrestrial life will be discovered within a decade or so, most were confident that intelligent life does exist on other planets in the universe. Fewer agreed that some form of life exists either on other planets in our solar system or on Mars in particular (see Figure 3).

Risks of Interplanetary Contamination

The need for planetary protection arises because of the possibility that Earth or another planet (or both) could be contaminated by the exchange of biological materials as the result of space missions. While

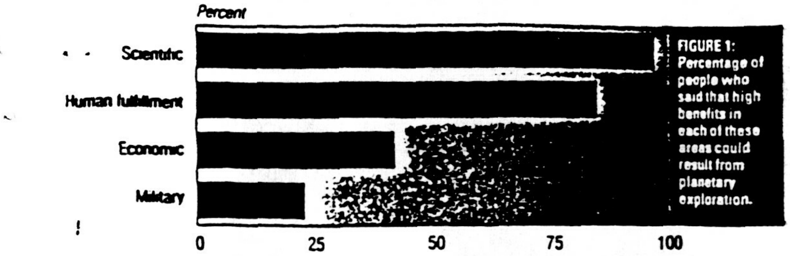

FIGURE 1: Percentage of people who said that high benefits in each of these areas could result from planetary exploration.

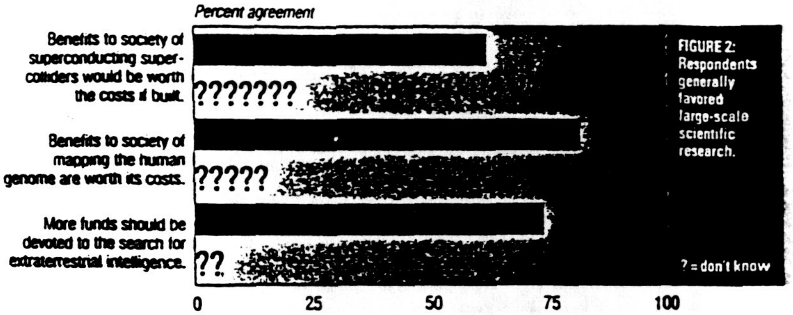

FIGURE 2: Respondents generally favored large-scale scientific research.

? = don't know

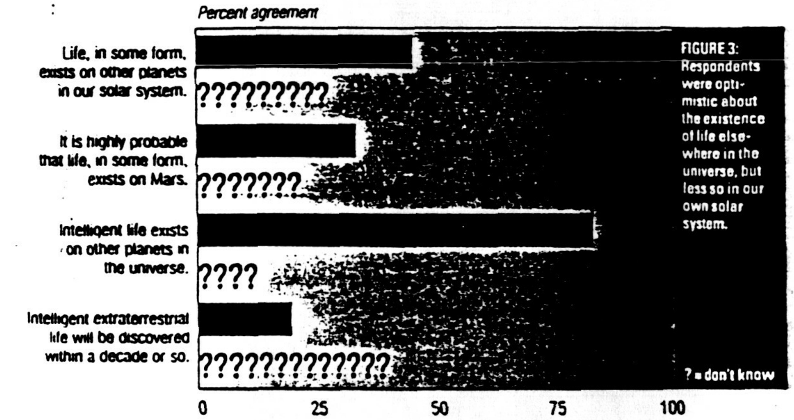

FIGURE 3: Respondents were optimistic about the existence of life elsewhere in the universe, but less so in our own solar system.

? = don't know

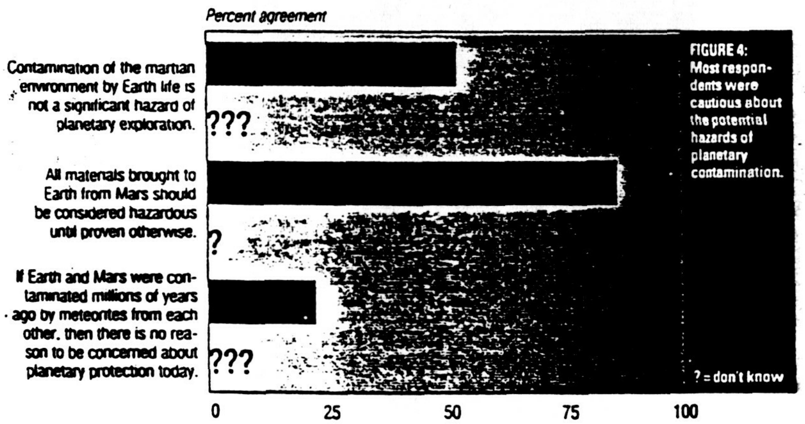

FIGURE 4: Most respondents were cautious about the potential hazards of planetary contamination.

? = don't know

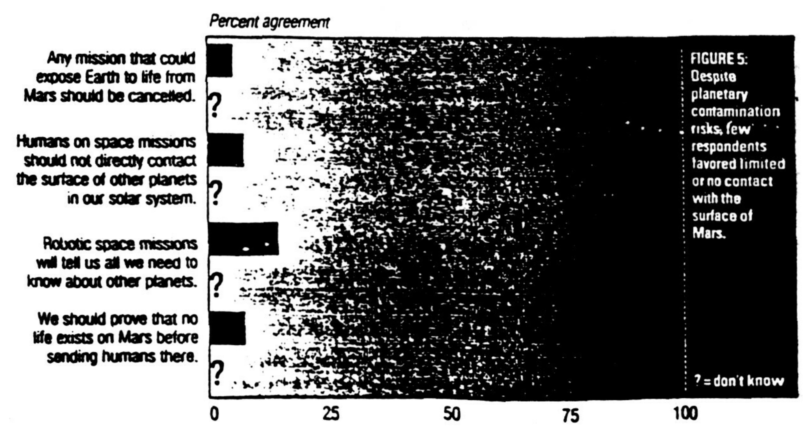

FIGURE 5: Despite planetary contamination risks, few respondents favored limited or no contact with the surface of Mars.

? = don't know

a slight majority of respondents thought that the contamination of the martian environment by Earth life is not a significant hazard, an overwhelming majority indicated that materials brought to Earth *from* Mars should be considered hazardous until proven otherwise.

One article in the special issue discussed a theory that Earth and Mars were contaminated millions of years ago by meteorites from each other (see "Swapping Rocks: Exchange of Surface Material Among the Planets," by H. Jay Melosh), suggesting that there may be no need for concern about planetary protection today. However, most respondents disagreed that concern was unnecessary even if such contamination actually did occur millions of years ago (see Figure 4).

Despite these views about the potential hazard of biological materials from Mars, there was a high level of support for future Mars missions. Very few respondents agreed that possible exposure of Earth to life from Mars was reason to cancel a Mars mission. Also, few agreed that humans on space missions should not directly contact the surface of other planets, or that robotic space missions will tell us all we need to know about other planets. Likewise, very few agreed that we should prove that no life exists on Mars before sending humans there (see Figure 5).

While planetary protection is intended to guard against inadvertent introduction of life either onto our planet or onto another planet, an important goal of space exploration is to study life elsewhere in the universe, if it exists. To do so may involve taking samples of life and returning them to Earth. Few respondents agreed that life on Mars, if it exists in any form, should be left there undisturbed. Even fewer agreed that it is morally wrong to bring life back to Earth from another planet or to introduce life from Earth onto another planet (see Figure 6).

Survival and Adaptability of Life

Whether life on Mars, if it exists, would survive on Earth and whether life from Earth would survive on Mars are important questions in the development of measures for planetary protection. Of all the items in the survey, those relating to the survival and adaptability of life received the highest percentages of "don't know" responses, indicating a high degree of uncertainty about these topics.

Among those respondents who did offer opinions, however, few agreed that the environment on Mars is too harsh to sustain any life from Earth. Likewise, few thought that life that evolved in the rich natural environment of Earth would not be fit enough to survive on Mars. Conversely, life on Mars was viewed as more fragile if brought to Earth.

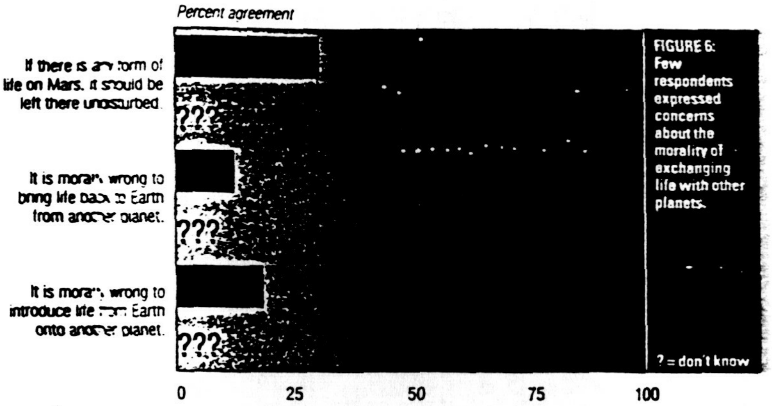

FIGURE 6: Few respondents expressed concerns about the morality of exchanging life with other planets.

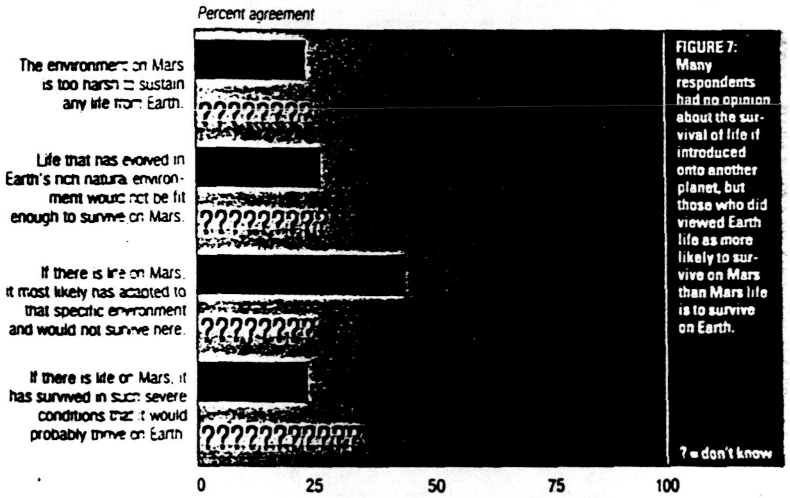

FIGURE 7: Many respondents had no opinion about the survival of life if introduced onto another planet, but those who did viewed Earth life as more likely to survive on Mars than Mars life is to survive on Earth.

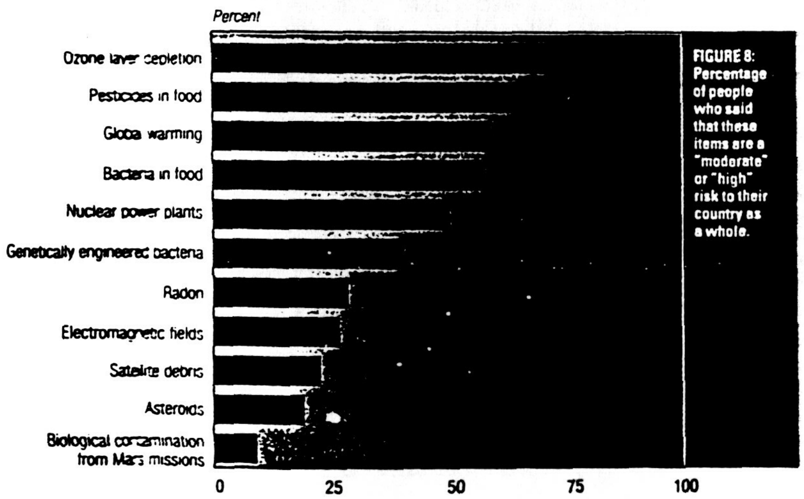

FIGURE 8: Percentage of people who said that these items are a "moderate" or "high" risk to their country as a whole.

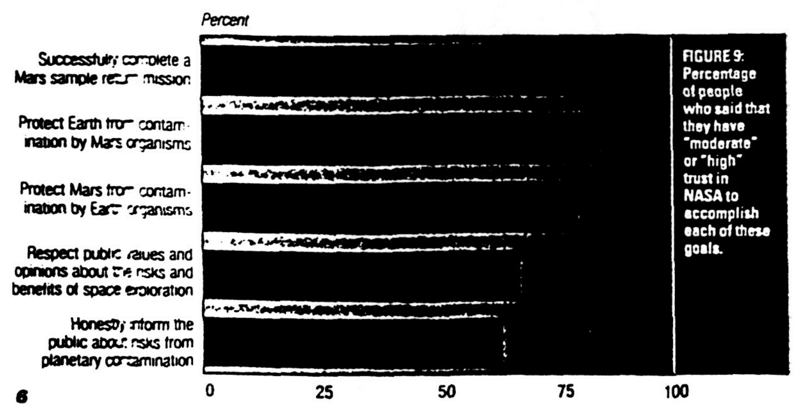

FIGURE 9: Percentage of people who said that they have "moderate" or "high" trust in NASA to accomplish each of these goals.

A majority of the respondents giving opinions about the ability of martian life to survive on Earth agreed that if there is life on Mars, it most likely has adapted to that specific environment and would not survive on Earth. Less than half (34%) agreed that it has survived in such severe conditions that it would probably thrive on Earth. Overall, respondents had an asymmetric view about the survival and adaptability of life—life from Earth was seen as more likely to survive on Mars than life from Mars was to survive on Earth (see Figure 7).

Rating the Risks

The potential contamination of Earth and Mars as part of space missions is just one among many risks faced by people on Earth. To put the risks of interplanetary contamination in a larger risk context, respondents were asked to rate the risks to their country from a number of different sources.

The highest perceived risk was ozone layer depletion, followed by global warming and food contamination (from pesticides and bacteria). Biological contamination from Mars missions was rated as the lowest risk, along with asteroids and satellite debris (see Figure 8). This does not mean, however, that these risks are of little or no concern to people. Indeed, at least half of the respondents indicated some level of risk for all of the items they rated, including those that ranked lowest.

Trust in NASA

In general, respondents had a high level of trust in NASA to successfully carry out a Mars sample return mission and to protect both Earth and Mars from interplanetary contamination. However, respondents were somewhat less trusting in NASA to respect public values and opinions about the risks and benefits of space exploration and to honestly inform the public about planetary exploration risks.

Though the percentage of respondents indicating "moderate" or "high" trust was over 50% for all items, the skepticism often voiced about the trustworthiness of government was echoed in these results as well (Figure 9).

To Sum Up

Overall, survey respondents were very optimistic about space exploration but cautious about the potential hazards of planetary contamination. As plans for future Mars missions move forward, public attitudes about managing the risks of space exploration will play an important role in the formulation of space policy. Your responses to this survey are a key to the development of a successful relationship between the public and organizations like NASA. Thank you for your contributions.

Donald MacGregor and Paul Slovic are senior research associates at Decision Research in Eugene, Oregon. Both are psychologists who specialize in the study of public attitudes about technological hazards.

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SOCIETAL ISSUES AS MARS MISSION IMPEDIMENTS: PLANETARY PROTECTION AND CONTAMINATION CONCERNS

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ABSTRACT

Societal and non-scientific factors represent potentially significant impediments for future Mars missions, especially in areas involving planetary protection. This paper analyzes public concerns about forward contamination to Mars and back contamination to Earth, evaluates major areas where lack of information may lead to uncontrollable impacts on future missions, and concludes that NASA should adopt a strategy that actively plans both the generation and subsequent management of planetary protection information to ensure that key audiences obtain needed information in a timely manner. Delay or avoidance in dealing with societal issues early in mission planning will increase the likelihood of public opposition, cost increases and missed launch windows. While this analysis of social and non-scientific considerations focuses on future Mars missions, the findings are also relevant for RTG launches, nuclear propulsion and other NASA activities perceived to have health, safety or environmental implications.

INTRODUCTION

Throughout its history, NASA has been concerned about planetary protection, the prevention of harmful cross-contamination of planets and other solar system bodies during space exploration. In practical terms, this concern focuses on two primary issues: *forward contamination*, the introduction onto a planetary body of terrestrial microbes carried on outbound spacecraft or equipment; and *back contamination*, the introduction onto Earth of contamination or life forms carried in return soils or samples. In the face of its proposed series of missions to Mars /1/, and in light of continuing scientific interest in the possible existence of life on Mars, NASA has recognized the need to intensify its focus on planetary protection associated with both mission planning and implementation. As noted by De Vincenzi and Klein /2/, a variety of technical, legal and political issues and public concerns must be evaluated before an official set of planetary protection requirements can be established for Mars missions, particularly for those with sample return. This summarizes an analysis of forward and back contamination concerns from both technical and public perspectives, evaluates the extent to which societal and non-scientific factors might represent potentially significant impediments for future Mars missions, and identifies key areas related to planetary protection that need further attention.

BACKGROUND

Concern for planetary protection is required by the Outer Space Treaty of 1967, which indicates that exploration and studies of outer space including the moon and other celestial bodies be done "so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from introduction of extraterrestrial matter."/3/ Over the years, views about planetary protection requirements have evolved as new scientific and technical information has been obtained from planetary research and exploration. These updated views have been reflected internationally in revisions of COSPAR planetary protection policies and within NASA by a series of Management Instructions and Policy Directives /4/. As discussed by De Vincenzi and Stabekis /5/, in the early 80's revised contamination control procedures were proposed that de-emphasized a quantitative probabilistic approach and introduced the concept of "target-planet" and "mission type" categories. These categories, still in use, are incorporated in NASA's current planetary protection policy (NMI 8020.7C, December 12, 1991) /6/.

In anticipation of future proposed Mars missions during the next two decades, NASA has sponsored a series of workshops /7,8,9,10/ that have intensified discussion about both forward and back contamination controls. These discussions have resulted in 1) reviews of the state of knowledge about Mars ambient conditions and implications for planetary protection and the search for life on Mars; 2) analysis of past experiences and current views about forward and back contamination requirements and practices; and 3) preliminary considerations of social and non-scientific factors relevant to planetary protection and mission success.

Forward Contamination Control--Experiences and Current Views

In considering forward contamination controls NASA has been able to build upon past planetary protection experiences from its earlier space programs. Valuable experience with forward contamination control was acquired in both the Mariner and Viking programs. Mariner flyby and orbiter missions, designed to meet the 1964 COSPAR planetary protection guidelines, were planned with cleanroom assembly of the spacecraft and careful trajectory selection to avoid forward contamination by premature impact on Mars /7/. The Viking program was NASA's first experience with landers under the COSPAR guidelines. Elaborate procedures involving cleanroom assembly, "sterilization" of landers, minimum periapsis altitudes for spacecraft, and additional heat treatment of biology instruments were undertaken. Post-Viking analyses have validated the effectiveness of contamination controls and their probable indirect contribution to the missions' success because of component reliability /10 (Appendix E) and 11/.

Current discussions about forward contamination control are centered mainly around the extremely low probability of growth of terrestrial organisms in the harsh martian environment and the question of whether Viking-like controls would be unnecessarily stringent and costly on future outbound missions /9/. At NASA's request, the Space Science Board of the National Academy of Sciences recently conducted a special review of planetary protection policy and practices and offered recommendations for upcoming Mars missions focusing particularly on forward contamination /10/. The Board's recommendations are based on the unanimous conclusion that forward contamination is not a significant hazard to the martian environment but could be a problem for future *in situ* experiments specifically designed to search for evidence of extant or fossil martian microorganisms. Their recommendations, which are made with reference to Viking control levels and procedures, distinguish between missions with and without life detection experiments and instrumentation.

Back Contamination Control--Experiences and Current Views

As reviewed by Bagby /12/, the Apollo Program was the first and only time NASA has dealt with back contamination concerns and sample quarantine for actual missions. Concern about planetary protection was expressed during the planning of Apollo missions and discussed in a special advisory conference by the National Academy of Sciences in July 1964. An Interagency Committee on Back Contamination was established in 1967 to advise NASA on procedures necessary to protect the Earth's biosphere from potential lunar contaminants. Extensive quarantine protocols were developed, a special biomedical facility was established to quarantine the astronauts, and a separate Lunar Receiving Laboratory was constructed for studying lunar samples. Even with elaborate protocols and facilities, Apollo's back contamination control program faced problems of effectiveness which, according to Bagby, were of two general types: 1) operational, such as those represented by the premature venting of a capsule or failure to follow established protocols; and 2) philosophical, such as flight crew resistance and conflicting intra-NASA authorities over planetary protection.

Organizational and management problems of the Apollo program were analyzed in detail by Mahoney /13 / who noted that the development of effective programs to prevent back contamination requires as a first step the clarification of responsibilities for and authorities necessary to accomplish specified goals. Although no special workshops or conferences about back contamination issues of either robotic or piloted missions have been convened since the Apollo Program, sample return missions and back contamination have been considered in hypothetical and conceptual terms in many published articles /e.g.: 2,14,15/. It is generally acknowledged that future discussions about back contamination controls are likely to encounter serious information gaps in scientific, technical, legal, institutional, organizational and other areas, making the formulation of back contamination controls more problematic than forward contamination controls.

NON-SCIENTIFIC AND SOCIAL FACTORS AS COMPLICATIONS

While Viking and Apollo experiences can provide general guidelines for many technical considerations about planetary protection, neither can be adopted on future Mars missions without considerable modification. Even when all the technical questions are answered, recommendations about planetary protection based purely on technical considerations may eventually play a secondary role in developing the final strategy for contamination controls, especially for back contamination /7/. Social concerns and non-scientific factors that were dormant or non-existent at the time of Apollo and Viking launches are likely to complicate mission planning, and in the worst case could become significant mission impediments with the potential to greatly increase costs, contribute to intense public opposition and lead to possible missed launch windows.

Socially driven concerns have already troubled NASA in the past. For example, both Galileo and Ulysses missions faced lawsuits seeking to delay or prevent the launches because of concerns about radioisotope thermoelectric generators (RTG's) and possible launch accidents. Forward contamination concerns were also raised in the Galileo lawsuit. These legal challenges occurred despite the fact that the missions were similar to many previous launches, included complete environmental impact analyses, and employed no new technologies. Future sample return missions could encounter even more intense scrutiny because of the public's concerns about possible introduction of extraterrestrial organisms onto Earth and the accompanying environmental, health and safety effects.

The literature is replete with examples of scientific and technical projects that were frustrated by public challenges and concerns. Retrospective reviews of controversial situations involving technologies as disparate as nuclear power, biotechnology, food irradiation, and toxic waste incineration have led to the identification of many underlying social and non-scientific concerns that can contribute to project opposition. Proposed Mars sample return missions bear striking similarities to the"Ice Minus" genetic engineering controversy, an outdoor experiment in the mid-1980's involving the first intentional release of an organism created by recombinant DNA technology. Published reviews provide a good historical analysis of events during the controversy as well as a lengthy discussion of the differences between scientific and public perceptions of the experiment /16/. The "Ice Minus" project involved field testing of genetically engineered bacteria to determine their effectiveness in preventing frost damage to agricultural plants. Opponents delayed the experiment for nearly five years through a succession of legal challenges and public policy maneuvers that kept the debate in the public spotlight. They characterized the proposed experiment as reckless because it used a truly "exotic" organism which, they claimed, had the potential to cause untold environmental problems if released. The controversy ultimately involved federal, state and local government agencies; legislative bodies and the courts; public hearings and environmental impact documents; and intense media coverage.

CHANGING EXTERNAL ENVIRONMENT AND PUBLIC EXPECTATIONS

Through retrospective study of "Ice Minus" and other situations of scientific-technical decision making in the public realm, it is possible to identify a number of non-scientific factors and social trends that have become important elements in public controversies about science and technology during the past two decades. While found predominantly in American examples, the factors and trends described below have implications for all current space going nations and are important considerations when planning planetary protection strategies, regardless of which agency or country controls the launch or return vehicle.

Dramatically Different External Setting

Future Mars missions will occur in a dramatically different external setting than those of earlier space exploration programs and are likely to encounter more public scrutiny and challenges. Conflicts within society about technological choices emphasizing hazards and risks have become an expected part of the public decision making realm over the past two decades /17 (Chapter 3)/.

Public attitudes about environment, health and safety have changed considerably since the Apollo program. As a generalization, society has grown more risk averse over time, with the trend expected to continue into the foreseeable future. These shifts in public attitudes about risks and technology have been matched by corresponding changes in law that have broadened the ability of citizens and groups to challenge public decisions. A host of new or restructured public institutions (e.g., Environmental Protection Agency, Occupational Safety and Health Administration, Office of Technology Assessment, Nuclear Regulatory Commission, etc.) were created during the past two decades that are charged with paying more attention to public goals and bringing technological decision making into the public arena. In addition, organized public oversight and vigilance has become institutionalized in the form of well-funded national and international groups that monitor government actions, lobby their political allies, conduct independent analyses, participate in regulatory decision processes, challenge government and corporate actions in court, and communicate with the public through the media. Because of the existence of many splinter opposition groups organized around single issues, it is often impossible to predict where challenges will surface or what focus they will take.

Changing Process of Decision Making About Scientific and Technological Risks

There has also been a gradual but substantial shift in the way public decisions are made about risks involving science and technology. As outlined by Fiorino /18 /, technological policy-making in a democratic society can be viewed in two different ways -- one dominated by technical considerations, the other by democratic and social values. The first decision making style, dominated by the experts, seeks objective standards in quantitative terms for determining the acceptability of risk, while the other, involving the lay public, emphasizes qualitative standards and value laden reactions to specific issues. In essence, current public decision making is caught in a perceptual shift somewhere between the traditional view of risk analysis as an expert process in which the lay public can occasionally intervene, and a newer view of risk analysis as a public political process that incorporates information and judgements from experts. Historically, NASA engineers and managers have been accustomed to reaching decisions through a highly technical, expert process with only minimal input from the public. However, decisions about planetary protection will undoubtedly impose a heavy load of social concerns onto mission planning, shifting the locus of decision making into a more public and democratic realm.

Simultaneous Controversies on Multiple Levels

Technical experts and the lay public often inadvertently focus on completely different questions at the same time with the same data. The experts typically gather information and perform risk analyses with the expectation of reaching an optimal or "right" decision. The public, on the other hand, often focuses more broadly on the societal context of the decision with the intention of preventing or stopping an action. Viewed another way, additional conflict is imposed because each group simultaneously focuses on different levels of the question. Often there are three typical levels or perspectives in a given controversy:

- *An ideological or public policy focus* dominated by philosophical questions of "should we do it?" and having an ethical or moral overtone (e.g., animal rights; nuclear opposition; food irradiation protests, etc.)

- *A focus concentrating on formulation of appropriate technical policies and procedures,* dominated by questions of "how should we do it?" and emphasizing a practical approach to decision making (e.g., formulation of government regulations; devising acceptable permit review processes; developing effective planetary protection controls, etc.).

- *A local focus* dominated by questions of "why do it here or now?" and characterized by the "NIMBY" syndrome (not in my back yard), (e.g., site selection for an industrial plant, building and operating a quarantine facility).

In extremely complicated situations, all three levels can be involved at once, mixing large societal questions and local opposition with the experts' tasks of assessing and managing the risks in a practical sense. This mixing of levels often results in accusations by the public that the experts are not listening, or complaints by the experts that the public is ignorant or uninformed.

Qualitative Factors Influence Risk Perceptions and Responses

A growing body of literature has dealt with the subject of risk perception and responses to risks, highlighting differences between experts' probabilistic approach to assessing risk magnitude and the public's contextual view of risk that emphasizes subjective factors /17, 19/. Studies suggest that people allow certain qualitative factors to disproportionately influence their perceptions of risk more than technical and quantitative features. Important characteristics associated with peoples' judgements and concern about risk have been identified by Covello et al./20/ and include whether the risk is perceived as familiar, understood, quantifiable, controllable, reversible, or dreaded. Other important factors affecting the public's perception of risk include institutional trust, accident history, effects on future generations, equitable distribution of risks and benefits, and media attention. It is noteworthy that future Mars sample return missions share many of the same qualitative features seen in the "Ice Minus" experiment, which generated high levels of public concern because it was perceived by the public as very risky despite the experts' assertions of low risk.

POSSIBLE IMPACTS OF SOCIAL AND NON-SCIENTIFIC FACTORS

With these four general trends in mind, I analyzed both forward and back contamination with the goal of identifying areas related to planetary protection that might be complicated by social and non-scientific factors. Special attention was paid to areas likely to be important to the public, especially adequacy of scientific knowledge, effectiveness of engineering technology and implementation, likelihood of media attention, adequacy of institutional and management arrangements, and areas of legal ambiguity or potential challenge. As described below, there are likely to be far more public concerns about back contamination than forward contamination.

Outbound Missions

All missions with one-way orbiters or landers will include planetary protection controls emphasizing prevention of forward contamination. Based on my analysis of the literature and presentations at NASA planetary protection workshops /7,8,9,10/, current concerns about forward contamination can be characterized as centering largely around maintaining the integrity of scientific experiments, minimizing contamination of the martian surface, developing updated sterilization and control techniques, and avoiding unnecessary added costs to the mission. There do not appear to be any major ideological concerns, technical policy questions, local controversies, or legal issues likely to incite major public outcry or media attention over lander or orbiter missions. At present, for missions with only outgoing spacecraft, the greatest potential for public concern is likely to center around Earth-focused environmental, health and safety issues like those seen in the Galileo and Ulysses missions. If public opposition is aroused, it is most likely to surface in the form of legal challenges brought under various environmental laws, especially the National Environmental Policy Act (NEPA) and its environmental impact statement requirements. Barring changes in laws or a dramatic shift in public attitudes about spaceflight, forward contamination issues alone are unlikely to generate the sustained media attention or intense public opposition sufficient to become impediments to future outbound missions.

Sample Return Missions

Future Mars missions with sample return raise many problems related to back contamination and global effects on Earth that are not encountered on one-way orbiter or lander missions. Major engineering and scientific questions must be answered before the public can be reassured that back contamination controls are effective and adequate. Among the technical and engineering problems to be solved are: design of the sample return canister with effective sealing and preservation to maintain the sample at Mars ambient conditions; how to break the surface contact with Mars and accomplish sterile insertion of the sample; development of a fail-safe system for monitoring the sample and canister during the long return flight ; methods and equipment for recovering, handling and transferring the sample upon landing; design, location, construction, and operation of quarantine facilities; and development of appropriate equipment and barriers for sample handling, testing, and storage /2/. Additional scientific information will be needed to answer questions about Earth-based sampling and testing, especially those related to operational protocols for the quarantine facilities, testing methods and experimental protocols for samples, development of appropriate bioassays, and curation and control of samples.

To overcome or avoid the intra-NASA management and organizational problems found by Bagby and Mahoney on the Apollo program /12,13/, special focus will be needed to develop precisely defined authorities and responsibilities within the agency for implementation of planetary protection controls. Considerable time must be also be allowed for completing the required environmental impact statements and permit processes, and for constructing quarantine facilities and performing the necessary testing and training for its use. Because other federal, state and local agencies may impose restrictions based on their respective legal mandates, interagency conflicts could be encountered. Legal challenges could become costly and time-consuming mission impediments based on issues such as environmental, health, or safety concerns; transportation and handling regulations; agency jurisdictional questions; human quarantines for those coming in contact with the samples; and international treaty obligations. Finally, the public's tendency to react strongly to perceived risks almost ensures intense media coverage and public scrutiny on all aspects of the sample return mission.

CONCLUSIONS AND RECOMMENDATIONS

Even though planetary protection is only a minor part of overall mission planning, it has the potential to become a significant mission impediment for sample return missions, especially if strategies for planetary protection are planned without serious consideration of non-scientific and social factors. Delay or avoidance in dealing with societal and non-scientific issues early in mission planning will increase the likelihood of public opposition, cost increases and missed launch windows. In order to minimize the prospects of disruption to future missions, NASA must proactively analyze and develop information in a number of key areas related to planetary protection, including:

Mission Architecture:

- Analyze current proposals for both robotic and human sample return missions to identify planetary protection concerns in each.

- Assess strengths and weaknesses of proposed mission architectures from legal, management , social or operational perspectives as they relate to planetary protection.

Legal:

- Include planetary protection and possible environmental effects of Mars missions "at the earliest stages of study and planning" as required by NEPA.

- Undertake a survey of domestic laws and regulations and international treaties to determine their applicability to sample return proposals.

- Determine whether establishment of another interagency review committee is advisable to coordinate and oversee the complex of laws and regulations that may apply to sample return.

Management:

- Develop a commitment to fulfilling planetary protection obligations at the highest level of NASA administration.

- Re-institute a significant Planetary Protection Program within NASA with sufficient budget to support needed research and development well in advance of sample return from Mars.

- Minimize avoidable operational problems with future sample return missions through early, comprehensive implementation planning with social and non-scientific factors included.

• Try to minimize philosophical opposition by educating NASA's technical and engineering community about the critical importance and necessity of planetary protection controls.

Research and Development:

• Begin early, selective R & D related to planetary protection prior to mission approval, especially in areas with long lead times such as sample collection, transfer, handling, and quarantine, as well as priority social and non-scientific concerns.

Risk Communication:

• Consider asking the National Academy of Sciences to conduct a scientific and technological study of the hazards involved in sample return for dissemination to the public and legislators.

• Keep the public informed and involved in planning and decision making for future sample returns from Mars.

In the current public and political climate, many questions about the advisability and design of the Space Exploration Initiative and future Mars missions remain hotly debated /21/. If NASA is seriously committed to future Mars sample return missions, whether robotic or human, it is important to acknowledge from the start the degree to which social and non-scientific factors could further complicate missions in unpredictable ways. While this analysis about social and non-scientific considerations focuses on future Mars missions, the findings are also relevant for RTG launches, nuclear propulsion and other NASA activities perceived to have health, safety or environmental implications.

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II. Abstracts

PLANETARY PROTECTION, LEGAL UNCERTAINTY AND THE DECISION MAKING PROCESS FOR MARS SAMPLE RETURNS

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Changes in the legal and decision making environments since the time of Apollo sample returns have provided the public with many ways to challenge or delay missions and their launches. As scientists, engineers, mission planners and administrators develop planetary protection requirements for future Mars missions, they must be mindful of the legal and public scrutiny likely to occur over environment, health and safety concerns, especially for missions involving sample return to Earth. To the extent that planetary protection questions are unresolved at the time of an actual mission, they offer convenient footholds for public challenges in both legal and decision making realms, over which NASA will have little control. Specific areas with the potential to complicate future missions include: uncertainty about institutional control and authority; questions about international treaty obligations; and constitutional and regulatory concerns about quarantine, public health and safety. In light of these important legal issues, it is critical that NASA consider the role and timing of public involvement in the decision making process as a way of anticipating problem areas and preparing for legitimate public questions and challenges to sample return missions.

FUNDAMENTAL STUDIES CONCERNING THE PLANETARY QUARANTINE IN SPACE

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Does solar planets are contaminated by terrestrial microorganisms carried with spaceprobes? We have studied on the ability organisms to survive under simulated Lunar and Mars conditions. The subject is not restricted to an academic curiosity, but concerns problems to prevent the contamination of outer planets with terrestrial organisms carried by spaceprobes. The interplanetary environment in solar system was simulated with wide range of temperature (100K~500K), high vacuum (10~1x10 [illegible] torr) by using a cryostat, ultraviolet irradiation and proton irradiation from a Van de Graaff accelerator. Several species of terrestrial organisms have been tested in our work. After the exposure to a simulated extraterrestrial circumstance, the survival rates of organisms were examined. Spores of *Bacillus subtilis* and some fungi showed considerably high survival rates even after ultraviolet irradiation and proton irradiation corresponding to a few hundred years in space.

F3.6 The Earth's Early Biosphere

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THE ECOLOGY OF EARLY ORGANISMS

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The ecology of early microbial communities might be reconstructed with greater confidence than any other ancient community since bacterial communities analogous to ancient ones persist in extreme environments. Relict bacterial communities develop in ecosystems where plants or even eukaryotes are absent. As typical relict prokaryotic communities those from hydrotherms, hypersaline and some other extreme habitats devoid of plants and animals are considered. Bacterial communities form trophical structure with cyanobacteria as usual edificators and that might be exemplified by analysis of relict communities. Sustainability of the community depends on the completness of cycling within community, which makes it a biogeochemical entity. Cycling presumes the existence of interlinked trophic groups of functionally diverse bacteria which are phylogenetically unrelated. This means that communities were constructed by combinatorial processes rather than by divergence from ancestral forms. In the Vernadskian approach based on the biosphere scale, survival of a species is possible only within community, not as a single species. Interaction of the community with the environment changes ecosystems in succession through evolutionary time and causes changes in the composition of communities. From the geological record it follows that cyanobacteria and, ipso facto, bacteria in their communities are quite persistant. That brings us out of conventional schemes of early evolution into domain of non-Darwinian conceptual framework of microbial community evolution within a dynamic biosphere.

BIOGEOCHEMICAL CYCLES ON THE EARLY EARTH

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Chemical fossils, among them the stable isotopes of carbon and sulfur, have been used successfully to unravel past metabolic pathways associated with the early evolution of life on earth. Thereby, results strongly depend on the degree of preservation.

Minimally altered organic matter (kerogen) displays an average carbon isotopic composition between -35 and -30 ‰ (PDB) throughout most of the Archean. This is likely determined by autotrophic carbon fixation, suggesting a maximum fractionation for the key photosynthetic enzyme RUBISCO. Unusually ^{13}C-depleted organics in several late Archean rock sequences, likely a result of a carbon cycle based on methane, are related to specific, possibly local environmental conditions. Unfortunately, however, severe thermal alteration of relevant Archean sedimentary rock sequences result only in a fragmentary age trend.

The sulfur isotopic composition of sedimentary sulfide, formed as a result of bacterial sulfate reduction, yields information about the process itself, its limiting factors and the geochemical environment of deposition. Analogues to younger deposits, variable but generally ^{34}S-depleted sulfides and a large isotopic fractionation between seawater sulfate and sedimentary pyrite have been interpreted as clear signs of bacterial sulfate reduction. Such evidence is detectable as far back as the Archean/Proterozoic transition (about 2.5 Ga ago). Interpretation of the earlier, Archean isotope record is rather controversial. Although the process of bacterial sulfate reduction might well have evolved by that time, geochemical evidence suggests that it wasn't the dominant source for sedimentary sulfide formation.

In summary, severe postdepositional alteration has greatly affected a large part of the relevant rock record. Thus, biogeochemical information concerning the early carbon and sulfur cycles is reduced towards a rather fragmentary record.

EARTH'S CRUSTAL ORGANIC CARBON RESERVOIR

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Crustal organic carbon reflects those processes which controlled the amount and oxidation state of carbon. On the prebiotic Earth, the mantle-crust exchange of volatiles created a crustal inventory of carbon and reduced inorganic compounds which reacted to give carbonates and organic matter. The environment's reducing conditions were attenuated somewhat by loss of volcanic H_2 to space. Once life began, it scavenged H_2 and retained its reducing power within the crust as reduced carbon and sulfur compounds. Thus, before oxygenic photosynthesis existed, the size of the crustal organic carbon reservoir largely reflected the redox state of volcanic emanations. Oxygenic photosynthesis arose perhaps prior to 3.0 billion years ago, liberating life from a sole dependence upon the reducing power of inorganic compounds. Photosynthetic organic matter which escaped recycling by bacteria was added to the crustal inventory. The oxidized products of photosynthesis then accumulated in the atmosphere, oceans and sediments as O_2, SO_4^{2-}, Fe^{+3} and NO_3^-. Their inventory was determined largely by processes which control the burial and preservation of organic matter in sediments. Among these, the rate of aqueous sedimentation of clays and other fine detritus is the most important factor. Nutrient availability is also important because it sustains primary productivity, and nutrients accompany organic matter during burial. Both sedimentation and nutrient availability are controlled by rates of rock erosion which, in turn, have been driven by the tectonic evolution of continents. Thus the crustal inventory of organic carbon reflects long-term interactions between Earth's mantle, crust, tectonics and life.