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PLANETARY PROTECTION ADVISORY COMMITTEE

January 12–13, 2004
Jet Propulsion Laboratory
Pasadena, California

MEETING REPORT

John D. Rummel
Executive Secretary

Norine E. Noonan
Chair

PLANETARY PROTECTION ADVISORY COMMITTEE (PPAC)
Jet Propulsion Laboratory
Pasadena, California
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Meeting Minutes
Table of Contents

Meeting Report Prepared By:
Robert J. Katt, Consultant
RS Information Systems, Inc.

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Monday, January 12, 2004

Welcome and Meeting Overview
Dr. Norine Noonan, Chair of the PPAC, called the meeting to order and welcomed the committee members, liaisons from Federal agencies, and other meeting attendees.

Center's Welcome
Dr. Thomas Prince, Chief Scientist at Jet Propulsion Laboratory (JPL), welcomed the committee and guests on behalf of JPL. He said that the laboratory staff and management are committed to the objectives of planetary protection (PP) and the technical basis for meeting them. JPL is now committed to investing in PP science and technology (S&T) and is interested in learning where the laboratory should be making those investments. Dr. Prince and others are looking forward to hearing the results from this PPAC meeting.

Planetary Protection Update
Dr. John Rummel, PPAC Executive Secretary, began by reviewing significant events for planetary protection since the committee last met (May 29–31, 2003). In June, the two Mars Exploration Rovers (MERs) were launched and the letter of agreement with the Japanese on PP issues related to the Nozomi spacecraft was extended. On July 31, notice of the draft Mars Sample Handling Protocol was published in the *Federal Register*. The Phoenix mission proposal was accepted as the 2007 Mars Scout mission on August 1. Details of Phoenix, which will collect a sample from the martian surface for return to Earth, were briefed to the PPAC later in the meeting. On September 21, the Galileo spacecraft was deliberately destroyed by impact with Jupiter, to protect against forward contamination of Europa or other jovian moons. This was the first time a mission has been ended this way to protect a solar system body. The course on PP policies and procedures for practitioners was given on November 4–6, 2003, at the Center of Marine Biotechnology (COMB) in Baltimore. Dr. Rummel reviewed the instructors who participated. The feedback from the students was very positive. The Mars Express spacecraft released the Beagle 2 lander on a Mars landing trajectory on December 19, but nothing has since been heard from Beagle 2, which was scheduled to land on December 25. Mars Express will begin sending back data from its Mars orbit soon. On January 2, 2004, the Stardust spacecraft completed its rendezvous with and sample collection from comet Wild 2. The next day, the first MER, Spirit, landed successfully in the Gusev Crater.

Dr. Rummel then reviewed upcoming events with PP significance, beginning with the landing of the MER Opportunity on January 24. A PP microbial detection and characterization workshop will be held in Cocoa Beach, Florida, in February. It will be the third in a series of workshops to qualify new standard methods for microbial detection sampling procedures. The new standards will be used to update NASA Procedures and [Requirements?] (NPR) 5340.1. The PP policies and procedures course will be given on the West Coast during the spring and then to the PP Interest Group of the European Space Agency (ESA). The international Committee on Space Research (COSPAR) will meet in Paris in July. In September 2004, Genesis will return solar wind samples, the first from space since the Apollo era.

MER Mission Status, Results, and Planning
Dr. Rummel reviewed the entry, descent, and landing (EDL) time line for the MERs, including what was known so far about events during Spirit's EDL. The unexpected thinness of the upper martian atmosphere will be taken into account in the EDL plans for Opportunity. The PPAC then saw the first 16 minutes of a televised live press conference with MER mission scientists and engineers. Egress of Spirit from its lander base petal is planned for sol 12.

Dr. Rummel reviewed the PP requirements (COSPAR Category IVa) that had been met by the MERs and the estimated bioburden of each spacecraft at launch. He reviewed the problem with spores in the foam backing of the fairing on MER-1 (MER-B). This problem has led to recognition that cleanliness requirements must be included in the launch vehicle manufacturing specifications. He reviewed other issues and lessons learned from the MER PP activities, including improvements to the dry heat microbial reduction (DHMR) process and installation of high efficiency particulate air (HEPA) filters in the aeroshell to prevent recontamination by the launch vehicle of the hardware to be landed. Dr. Noonan and other PPAC members discussed with Dr. Rummel and Ms. Laura Newlin, of the MER planetary protection compliance team, the issues with improving the manufacturing process for parts like the acoustic foam layer of the fairing. Other topics discussed were the assembly and cleaning procedures and possible factors in the fairing contamination. Ms. Newlin noted that the PP implementation plan for the MERs included use of DHMR on 48 percent of the items in each spacecraft.

Planetary Protection Update, Continued
Dr. Rummel continued with the status update on PP by listing issues before the PPAC in the areas of forward contamination, back contamination, and implementation of new monitoring and microbial removal methods. He related these issues to the agenda for the meeting. The first day's presentations led up to the committee's discussion of PP requirements for the Mars Science Laboratory (MSL). Dr. Rummel summarized the relation of a theory of martian ice ages recently published in *Nature* to the evidence for geologically recent events of water movement, glaciation, and erosion on Mars. The changing picture of the role of water on martian geography has, over time, affected the recommendations from the National Research Council's (NRC's) Space Studies Board (SSB). The SSB is starting a new study on forward contamination of Mars, which will take the recent evidence and related theorizing into account.

Dr. Rummel reviewed upcoming solar system exploration events and their PP implications, including Cassini/Huygens (the Huygens probe will impact on Titan), sample returns by Genesis and Stardust, the collection of comet nucleus material by Deep Impact, and the Jupiter Icy Moons Orbiter (JIMO) mission. He also reviewed the action and follow-up items from the May 2003 PPAC meeting, with responses and current status for each item. Many of the PPAC's items, as well as questions from Dr. Debra Leonard (included in the May 2003 meeting report as Appendix E), will be addressed by presentations during this meeting.

The PPAC members discussed several continuing issues, including the validity of NASA's standard microbe assay method as a reliable indicator of the extent of contamination by anaerobes and other nonculturable spores or vegetative microbes. Another issue was the use of microscopic examinations to assess total bioburden and how proposals for such studies of assay methods could be solicited from the science community. Dr. Eugene Levy and other members suggested that NASA needs a planned research program in these areas and should not rely on unsolicited proposals. Dr. Rummel asked the PPAC to consider and suggest ways to build up a more organized program approach, including a research program, that would go beyond earlier recommendations favoring the Viking DHMR standard. He mentioned some of the issues that had to be addressed to develop and adopt new standard methods that are technically feasible, reproducible under practical working conditions, and robust when integrated into spacecraft development and assembly processes. He noted that these new standards will need to be available for use with MSL and subsequent Mars sample return (MSR) missions. The level of interest in PP issues from the Office of Science and Technology Policy (OSTP) was discussed.

MRO Status and Planning
Dr. James Graf and Kirk Breitenbach briefed the PPAC on the status of the Mars Reconnaissance Orbiter (MRO) mission, including PP planning. Dr. Graf explained how the science strategy for MRO continues the overall Mars exploration strategy of "following the water." MRO science objectives include characterizing past and present climates on Mars, determining surface and subsurface structure and composition, identifying and characterizing prime sites for future exploration missions, and providing a communications link for missions to be launched in 2007 and 2009. MRO launch is planned for August 2005. Its interplanetary cruise will take 6 to 7 months, followed by 6 to 7 months of aerobraking to lower the orbit to the level desired for the science objectives. The science and communications relay missions will continue for 4 years.

Because the MRO orbit is considerably lower than other Mars orbiters (320 x 255 km) and the spacecraft is large, the PP approach is to control the total spore burden within PP limits. Dr. Graf reviewed the size and structure of the MRO and its fuel and instrument payload, compared with Mars Odyssey and Mars Global Surveyor (MGS). MRO will be able to resolve 1-meter features on the surface, which is important for landing site selection for MSL and later missions. Off-nadir viewing will be possible for targeted observations at high spatial resolutions. The High-Resolution Imaging Science Experiment (HiRISE) telescope and Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) are the MRO's two high-resolution instruments. MRO will return a much larger volume of data (about 26 terabits) than previous Mars orbiters. One issue is the capacity of the Planetary Data System (PDS) to absorb this amount of data. The intent is to expand the spectral measurements (a full global survey using CRISM in survey mode) and spatial measurements of Mars to a new resolution regime.

MRO passed its critical design review in May 2003 and is more than halfway through development. It is now in the primary facility for starting assembly, test, and launch operations (ATLO).

Mr. Breitenbach discussed the details of the PP approach for MRO. The spacecraft must comply with NPR 8020.12B for a Category III mission. A total bioburden approach is being used for the allowable number of spores on the accountable portion of the spacecraft. There will also be stringent control and accounting of bioburden on portions of the spacecraft that would reach the surface of Mars, in the event that the spacecraft crashes, without being sterilized by sufficient heating. These more stringent cleaning and bioburden accounting procedures are not applied to portions of the orbiter that would reach sterilization conditions (time and temperature) during an entry and breakup event. The spore content estimation and verification procedure entails component-by-component accounting of spore contributions, based on a master equipment list, with accounting for volume and area spore burdens by material type, manufacturing environment, and microbial assays. Mr. Breitenbach described the breakup and burnup (B&B) analyses that have been used to determine which hardware components would and would not reach sterilization conditions in the event of atmosphere entry and breakup during the mission period. These analyses use three phases of B&B: orbiter decomposition into modules with separate trajectories, a middle decomposition phase, and a component heating phase for non-ablated components. The models used in the B&B analyses incorporate heritage codes from breakup of spacecraft entering Earth's atmosphere. The result of the analysis is a list of nonsterilized components, which are the potential spore carriers on which bioburden must be controlled. The bioburden estimate for these components is in the range of 4.2×10^{-5} to 4.75×10^{-5} spores, depending on the aerodynamic scenario. Mr. Breitenbach described this bioburden estimate as a worst case (maximum) bioburden and reviewed the elements of conservatism in the analysis.

Mr. Breitenbach listed lessons learned about using this PP approach, including the importance of starting the PP planning early in the mission concept development and working closely with the PP Officer. Other lessons included the following. (1) Use actual assays of flight hardware where possible (rather than relying on traditional estimates, which are often conservative). (2) Many modern detectors and optical designs are incompatible with DHMR and/or current standard assays. Electronics are more robust, but the effects of prolonged heating must be assessed for each component. (3) PP activities can be expensive and can divert resources at critical junctures. Mr. Breitenbach suggested that more options for spore assessment are needed to enable PP compliance at a reasonable cost.

During the question period, Dr. Graf and Mr. Breitenbach discussed with PPAC members the uncertainties in the analyses and assumptions and the extent to which the uncertainties are fully covered by conservatism in the estimate. PPAC members expressed concerns about the connection between the B&B modeling and validation of the codes with actual results, particularly with respect to determining which parts of the spacecraft would reach sterilization conditions through aerothermal heating. They also discussed the origins of the lifetime probability requirement (originating in COSPAR and SSB recommendations to NASA and to the United Nations Committee on Peaceful Uses of Outer Space). Dr. Rummel said that he has asked the SSB to consider again the issue of forward contamination requirements (bioburden limits).

MGS Status and Results

Dr. Arden Albee, MGS Project Scientist, highlighted the successes of the MGS mission, which has performed a global mapping of Mars, using synergistic instruments to gather data continuously about the atmosphere, surface, and interior. MGS has been returning data for more than six years, with more than 700 gigabits of data archived. Dr. Albee described similarities and differences between Earth and Mars with respect to atmosphere and climate and their interactions with surface features. He reviewed the mission's science objectives, spacecraft parameters, and instrument payload.

The PP requirement applied to MGS was the lifetime probability limit for reaching the surface. They began planning for the aerobraking procedure to bring MGS into the desired science orbit with only a limited knowledge of Mars' atmosphere and gravitational field. A phased approach to aerobraking was used, with a hiatus after the initial phase to adjust for the experienced atmospheric and gravitational conditions. The orbital operations have been so successful that the nominal 2-year mission could be extended until 2015. A major MGS contribution has been a global map of the martian magnetic and gravitational fields. To illustrate other contributions made by MGS, Dr. Albee contrasted the geochemical and spectroscopic picture of Mars circa 1992 with the picture resulting from MGS and other missions since then. The Mars Orbiter Camera (MOC) showed that sedimentary rocks are widespread and provided clear evidence for subsurface water or ice throughout much of Mars' history. Many of the MGS instruments have contributed significantly understanding the martian atmosphere. Dr. Albee concluded with the contributions of MGS to Odyssey and MER and the plans for fuel use and MGS positioning to enable an extended mission.

Mars Odyssey Status and Results

Dr. Jeffrey Plaut briefed the PPAC on the Odyssey mission. Odyssey has been in Mars orbit since October 2001, and its nominal science mission continues until August 2004. Dr. Plaut reviewed the science objectives and the three instrument suites used for them: the Gamma Ray Spectrometer suite (GRS), Thermal Emission Imaging System (THEMIS), and Martian Radiation Environment Experiment (MARIE). He discussed results of explorations for hydrogen, as an indicator of water, using the neutron spectrometer in the GRS. The form of the hydrogen is not known. Results from MARIE are in a radiation dose equivalent, using the same dose equivalence used by instruments on the International Space Station (ISS). The results to date indicate the radiation dose is only about double that in the low Earth orbit of the ISS (which is protected by Earth's radiation belts). Dr. Plaut displayed some of the mineral maps produced with THEMIS, which has also been valuable in characterizing landing sites for MER and other missions. Simultaneous THEMIS observations will be made at the sites where the MERS take samples. The Odyssey ultrahigh frequency radio (UHF) system is also serving as a communications relay for MER data. Odyssey is in a stable orbit for an extended mission beyond August 2004, if NASA Headquarters approves the extension. Dr. Plaut described the science objectives that would be undertaken with an extended mission.

Committee Discussion: Future Mars Requirements and PPAC Advice

As a review of current PP policy and requirements for future Mars missions, Dr. Rummel summarized the COSPAR PP mission categories and noted that NASA has agreed to abide by COSPAR policies. The PPAC discussed the wording of the COSPAR requirements for Category IVa, IVb, and IVc. With respect to the second option provided under Category IVb, Dr. Rummel explained that the driver for defining Category IVb was to avoid false positives in looking for signs of life on Mars, not to protect Mars from contamination. Category IVc, by contrast, is for martian special regions, as defined by COSPAR. He also reviewed the Category V requirements for samples returned to Earth from Mars. Forward contamination from any part of a spacecraft is more of an issue for a special region because of the risk that microbes could not only survive but multiply under suitable conditions. Issues the PP Office faces in implementing current Mars PP requirements and policy, or in setting new policy, include: (1) the level of bioburden on outgoing spacecraft headed to Mars, (2) the level of bioburden that could reach the martian surface or subsurface from either a landed spacecraft or parts after a crash, (3) implementation of Category IVc if a Mars lander includes a perennial heat source, and (4) handling unsterilized samples returned from Mars to Earth and preserving them for scientific study.

Dr. Noonan said these PP issues should be viewed in light of questions PPAC members had raised during the morning's presentations. These questions involved: (1) issues of unknown unknowns; (2) what does "clean" mean, if we don't understand what is there, beyond culturable aerobes? (3) are the orbital lifetime requirements still acceptable, given new knowledge about extremophiles? and (4) the factual basis underlying analyses used in determining survival of nonsterilized spacecraft components in the event of an orbiter failure (B&B analyses). Dr. Debra Leonard and other PPAC members asked about the kinds of controls that are included when sampling or analyzing for life or signs of life on Mars. They suggested that missions whose samples might be used for such analyses, whether or not designed for doing so, should include capability for full-procedure blanks (a blank that goes through all of the environments and procedures of other samples collected for analysis, but without exposure to a collected martian sample or to the martian environment). Dr. Laurie Zoloth and other members discussed the basis for expanding Mars exploration in light of the possibility for “unknown unknowns.” Dr. Rummel said that the decision to have any type of Mars exploration program implies the acceptance of some level of risk of [forward] contamination. Dr. John Kittredge remarked that the importance of having adequate controls, such as procedural blanks, emphasizes the importance of knowing what the standard assay methods (e.g., culturable spores) indicate with respect to total bioburden, including nonculturable microbes. Dr. Noonan summarized this discussion of unknown unknowns, saying the question to be asked is whether the NASA research program for PP is robust enough to give a rational level of confidence that the potential risks are within a level that we are willing to accept.

Phoenix Status and Planning

Dr. Peter Smith, Phoenix principal investigator, and Mr. Barry Goldstein, Phoenix project manager, briefed the PPAC on the status and planning for the Phoenix mission, which has been selected as the 2007 Scout mission. This landed mission to the northern plains of Mars is intended to determine the habitability of the icy soil there and establish ground truth for orbiter observations (e.g., data from the Odyssey mission) indicating the presence of water. Dr. Smith said the mission will try to sample a location where organisms might not be active today but might be dormant. The Phoenix concept uses an existing Mars lander spacecraft (from the Mars Polar Lander mission) and existing instruments. The three broad science goals are to study the history of water in all its phases with paleo-hydrologic, geological, chemical, and meteorological methods; search for habitable zones by characterizing the subsurface environment in a region of permafrost, and study the weather and climate of the martian arctic region. Dr. Smith explained the criteria and analytic approach that will be used to select a landing site: a flat region with icy regolith or ice accessible by excavation, low altitude, and safe for the lander. A key part of the payload is the robotic arm to dig into the soil at the lander site to collect a sample. During discussion with PPAC members of how the samples would be collected, Dr. Smith emphasized the PP issues in digging for and preparing a sample for analysis by the Microscopy, Electrochemistry, and Conductivity Analyzer (MECA) and Thermal Evolved Gas Analyzer (TEGA), the analytic instruments in the Phoenix payload. MECA will perform wet chemistry analyses as well as microscopic examination, but will not test for organics. TEGA heats the sample gradually, with volatiles analyzed by mass spectrometry. In response to questions, Dr. Smith described the energy and power available for digging into the surface, the magnification available for microscopy, and the temperature range during the digging phase. To deal with the irreducible background of organics on and in the spacecraft components, the team will examine a series of samples collected by digging in the subsurface, looking for an increasing gradient of organics with depth. There will be four MECA samples and eight TEGA samples collected and analyzed.

Mr. Goldstein described the partners on the project team; the development timeline; the spacecraft; and its entry, descent, and landing on Mars. The mission will be PP category IVc because the lander will be in a special region. The PP plan is based on the 2001 Mars Polar Lander PP plan. The PP challenges include implementing the biobarrier for the robotic arm and the spacecraft integration procedures to meet the Category IVc requirements. Mr. Goldstein presented the plan for developing the biobarrier and answered members’ questions about the biobarrier concept and how it will be implemented. Mr. Goldstein noted that major engineering challenges involved in meeting the IVc requirements apply to other missions, as well as to Phoenix.

MSL Science Planning

Dr. Frank Palluconi, MSL project scientist, began with the relationships of the MSL project to the science community through the instrument acquisition process, the MSL Project Science Integration Group (PSIG), MSL supporting investigations, and the Next Decade Mars exploration pathways. He then described the instrument suites in the science payload, the science strategy, and the plan for controlling organic contamination. MSL science options were defined and prioritized by the MSL PSIG, which defined the overarching science objective as conducting a habitability investigation to achieve breakthrough science in astrobiology. The PSIG defined habitability as the potential of a given environment to support life at some time and said “habitability is synonymous with “capacity to sustain life.” The PSIG vision for MSL was to add an analytic laboratory to a rover and use the mobility and long life enabled by a nuclear energy source to examine multiple samples from multiple locations. Instrument selection will be based on suitability for the four investigations the MSL will conduct: assessing the biological potential of at least one target environment, characterizing the geology of the landing region at multiple spatial scales, investigating planetary processes of relevance to past habitability, and characterizing the broad spectrum of surface radiation. The MSL's instrument suites include remote sensing, contact instrument sensing, and laboratory-like sample analyses. The first two suites have a primary operational role (supporting decisions on what to do with MSL's analytic capability), as well as an observational/scientific role. The science strategy includes criteria for site selection and criteria for selection of samples to be analyzed with the laboratory analysis suite.

The NASA Mars Program Office chartered an Organic Contamination Science Steering Group to define the organic contamination problem and suggest solutions. This steering group established the levels of contaminants of concern that could be tolerated without compromising the MSL science objectives. MSL is a transition mission, in the sense that it includes elements of geology and climatology science while emphasizing definitive geochemistry and searching for all forms of carbon. In answer to Dr. Kerridge's question on whether MSL's assessment of "habitability" applied to Mars globally or just to a local region, Dr. Palluconi said that the scope of the habitability assessment would depend on the type of landing site selected.

<u>MSL Project Status</u>
Mr. Mike Sander briefed the PPAC on the context for the MSL mission, the key drivers, and the mission architecture as incorporated in the current reference design for MSL. He said that PP needs are part of the programmatic requirements of the mission and will entail trades with science mission needs. Key assumptions are (1) nuclear power will be available for MSL, and (2) a communications relay link to the Earth will be available via a telecommunications satellite. The MSL EDL includes two phases of parachute descent, the first at supersonic speeds, the second at subsonic speed. After the subsonic parachute descent, onboard radar and rockets will allow it to maneuver to a desirable landing site. The rover, which has been tucked up under the descent stage, will be lowered on a rope while the descent engines fire. In the "sky crane" phase, the rover will land on its wheels as the ascending rocket stage flies off and, several seconds later, crashes away from the rover's landing site. There is a substantial technology development program to support this EDL scenario.

The rover has two arms for collecting samples. The mass allocation for each of the two radioisotope power systems (RPSs) is 40 kg. Each RPS produces 110 W electric and 500 W heat. This heat output is essential for sustaining the instruments over an extended mission life. A Mission Concept Review in October 2003 responded positively to this reference design but raised significant concerns about cost risk, including PP unknowns. Although the project has moved into phase A, the reference design exceeds the cost limit by $70 million. Mr. Sander reviewed the project schedule from the Mission Concept Review through the development-phase design reviews to launch, Mars landing, and end-of-mission. If MSL is solar powered, end-of-mission is six months after landing. If it is nuclear powered, the nominal mission time can extend to nearly two years.

PP has been the primary mission issue highlighted in the monthly reviews, particularly because the heat from the RPSs could increase contamination risks if the landing does not occur as planned (an off-nominal landing). A water-containing area could be heated indefinitely by the RPSs while also being in contact with contaminated rover components, increasing the risk of Earth microbes reproducing in some portion of the heated area. At present there is no clear-cut solution for meeting the PP requirements within the current cost-constraints. The project team is using a systems engineering approach—making trades to meet all the constraints including the PP requirements and cost.

Dr. Noonan expressed a concern that the project was moving too far toward development decisions without having a viable PP solution. Mr. Sander said that the team believes there are solutions within the trade space defined by the constraints. Also, there are several decision points along the project schedule at which the project could be delayed (pending resolution of issues) or ended. In response to a question, Mr. Sander and PPAC members clarified that the RPS risk is related to heating a water-containing zone (in particular, a subsurface volume of ice-containing soil), rather than a radiation hazard.

MSL Planetary Protection Study and Discussion
Brian Muirhead of the MSL project team expanded on the approach being taken to meet the Category IVc PP requirements for MSL and for other prospective Mars Program lander missions that might follow MSL. The issues and context that lead to the PP constraints on MSL apply to all of the next generation of Mars surface missions. As Mr. Muirhead phrased the larger issue for the Mars exploration program, the Viking level of bioburden cleanliness ("sterilization") was driven by the Viking objective of searching for extant life. For missions with scientific objectives other than looking for extant life, options other than a Viking sterilization level of cleanliness are needed. MSL and future lander missions are dealing with a different PP context than earlier missions faced because of the "Mars special region" concept and the associated PP Category IVc, which requires addressing the risk of an off-nominal landing in a special region.

Mr. Muirhead is currently working on a study paper for Dr. Rummel, which includes a decision tree for representing successful controlled landing and off-nominal landings with a perennial heat source (such as the proposed MSL RPSs). The paper will also present options for achieving cleanliness levels using DHMR and for organic cleaning and microbial reduction for each step in the chain for collecting and analyzing samples. Mr. Muirhead described the probabilistic approach he is taking in the engineering analysis, the working definition of DHMR, and MSL's pathfinding role with respect to PP technology for future missions. In the decision tree for off-nominal landings, the difficult branches for analysis are those in which RPS elements are near or buried with contaminated materials The stochastic analytical models he is using require specific quantitative values that can be used as the basis for estimating acceptable risks. He asked the PPAC for advice on the values he should assume—for example, the acceptable probability that a microzone capable of breeding Earth microbes carried on the lander would be created by an off-nominal landing (a "warm puddle" scenario). A key issue is whether the entire MSL rover has to be at a Viking level of cleanliness, or only those parts (sample collection arm, analysis train, etc.) that would come into contact with sample material during normal operation.

The vehicle breakup analysis he is using is the same one used for MRO, the MER mission, and other Mars missions. The breakup sequence during EDL leads to a number of distinct failure modes to be assessed, and Mr. Muirhead discussed his results to date in assessing them. Parachute failure modes during the descent phase appear to be the greatest concern (with respect to forward contamination probabilities). Penetration into icy soil of the general purpose heat source (GPHS) after impact could result in creation of a wet layer in contact with the GPHS or separated from the GPHS by a dry soil layer (due to water sublimation around the GPHS).

Ms. Laura Newlin described the preliminary bioburden budget for MSL, which has been developed using the MER project as a model. This budget uses DHMR where feasible to lower bioburden. Based on this preliminary work, the encapsulated electronic assemblies are the principal source of bioburden, and the MSL reference design rover would exceed the Category IVc limit on bulk bioburden. However, this result assumes the standard spore density values specified in NPR 8020.12b. With additional use of DHMR—for example, on electronic assemblies—she believes the hardware reaching the Mars surface on a successful landing (planned impacting hardware) will meet the IVc requirement. However, additional work will be needed to meet the requirement for an unplanned impact (Muirhead's off-nominal landing cases). An issue for the option of system-level DHMR is that heating to 110 °C ambient for 20 hours may not yield four orders of magnitude reduction in assayed (culturable) spores. If the time at 110 °C ambient needs to be increased (for example, to 200 hours), materials and particularly interfaces would be much more affected. The PPAC members discussed with Ms. Newlin the items on her preliminary list of tasks to implement a system-level DHMR. Mr. Muirhead then concluded the presentations with the next steps in completing the white paper and having it reviewed by outside, independent experts. He repeated his request for advice from the PPAC on quantifying the probabilities implied in the category IVc requirements as stated by COSPAR.

Committee Discussion, Mars Requirements
After the presentations on MSL PP planning, Dr. Rummel and the PPAC members discussed the reasonableness of different approaches to applying probabilistic analysis to MSL landing scenarios. Dr. Rummel said a probabilistic analysis that begins by assuming a crash occurs (what happens in the event of an off-nominal landing) seems reasonable, whereas attempting to include the probability of a failure

occurring in the overall probability of contamination would not be a reasonable approach. Dr. Noonan affirmed this point, saying that the question before the PPAC is what happens *when* a mission crashes on Mars. Dr. Zoloth suggested that being overly conservative at this time might be reasonable, if it allows the project (and the Mars exploration program) to proceed until more is known about habitability in martian environments. Mr. Muirhead said that the difficulty in being overly conservative was the prohibitive cost for the project. He suggested a return to the fundamental issue of the acceptable risk of contaminating Mars, as it was raised prior to the Viking-era allocations of contamination probabilities among the space-faring nation and among each nation's mission spacecraft.

Dr. Noonan suggested that the issue of unknown unknowns was still too substantial for PP planning to abandon a very conservative approach. She emphasized that NASA should accept the cost of developing improved PP technology (such as feasible means of system-level "sterilization" and more realistic indicators for total bioburden) as a program cost (or space exploration cost, even broader than a single program line), not as a cost the MSL project alone should bear. Dr. Levy questioned whether a warm puddle scenario would contaminate Mars globally or would even have a probability of doing so that is a reasonable concern. This led to a discussion among the members of the impact of the warm puddle scenario—if it were to occur—on Mars exploration, the ultimate objectives of planetary protection, and public support for continued exploration of Mars (and the solar system). The members also discussed whether and how cost should be a factor in the committee's recommendations on planetary protection and bioburden issues and what types of outcomes should count as an unacceptable contamination of a planetary body. The trade-offs in science scope for doing the MSL mission without a perennial heat source were discussed. Dr. Rummel reviewed the scope of the PPAC's charter to advise the Associate Administrator of the Office of Space Science on planetary protection issues. The PPAC can also play a role in contributing to international standards that safeguard planetary science investigations through recommending what NASA should bring before the COSPAR.

Dr. Noonan summarized the major issues that had surfaced in the discussion. She advised Mr. Muirhead to go forward with completing the analyses as planned. The resulting report will contribute to the debate prior to the several decision points about continuing, revising, or suspending the mission as currently conceived. The MSL team members present described the impact that current assumptions would have on the next year of mission conception and planning. After further discussion of the committee's role in assessing whether PP risks are prudent or not, the discussion was adjourned until Tuesday's session.

Tuesday, January 13, 2004

CAIB Report and Contour Mishap Report

After reviewing the agenda for the day, Dr. Rummel briefed the PPAC on the final report from the *Columbia* Accident Investigation Board (CAIB). He highlighted points in the report that might be relevant to PP issues. (Full copies of the report, which are available online at the NASA website, were distributed to the members at the beginning of the meeting.) The CAIB concluded that the proximate cause (physical cause) for the loss of Columbia was a breach in the Thermal Protection System (TPS) on the leading edge of the left wing. The breach was caused by a piece of insulating foam, which had detached from the bipod ramp section of the external tank during launch and struck the wing's leading edge. Foam strikes on the wings had occurred previously without a problem. The CAIB also detailed the organizational factors, rooted in the history and culture of the Shuttle program, that contributed to the accident. Cultural traits and organizational practices detrimental to Shuttle safety were allowed to develop. Many of these related to failure to sustain the good engineering practices appropriate to the Shuttle's status as a developmental system, rather than an operational vehicle. The PPAC discussed the CAIB recommendations on organizational changes, with members agreeing that the recommendations on flight deadlines meant that, if the program lacked the resources (funding) to do the plan correctly, then it should not go forward. Dr. Rummel also emphasized the recommendations for expanded training of Mission Management Teams and establishment of an independent Technical Engineering Authority. He compared the role of the Technical Engineering Authority to the roles in planetary protection of the Planetary Protection Office.

In his comments on the report of the Mishap Investigation Board (MIB) for the loss of the Comet Nucleus Tour (CONTOUR) spacecraft while leaving Earth orbit, Dr. Rummel gave an overview of the mission and the context of the failure. The fatal mishap occurred at the end of a burn by the solid rocket motor, which was located with spacecraft operational components arrayed around it. The MIB concluded that the probable proximate cause was overheating of the forward end of the spacecraft due to base heating from the solid rocket motor exhaust plume, leading to material weakening and structural degradation. As root causes of the mishap, the MIB cited the project's reliance on analysis by similarity, which overlooked a crucial error in the design documents that left inadequate clearance from the rocket nozzle, an inadequate system engineering process, inadequate design review, and other factors. The set of six lessons learned emphasized care in the use of heritage elements and supporting analyses, communication across all project elements throughout the developmental phases, careful and systematic documentation of all engineering work, and re-examination of the level of NASA oversight for missions led by a university-based Principal Investigator (PI).

MER Project Press Conference

The PPAC listened to about 20 minutes of a live press conference on progress in disembarking the Spirit MER from its landing base petal. The project team described the surprises in upper atmospheric conditions and surface winds that had been encountered during EDL. Afterward, Dr. Noonan remarked that she was struck by what could happen that was not expected, even in a mission that had been very carefully planned by the project team's scientists and engineers.

Mars Sample Return Mission Concepts

Dr. Richard Mattingly of the Solar System Exploration Advanced Studies Office, JPL, reported on the status of mission studies for MSR. He began by reviewing the baseline science objectives in 2001, when the studies began. Those objectives included returning a sample of at least 500 grams, assuring sample diversity by using surface mobility during sampling, a sample from a depth of at least 2 meters, and draft PP requirements expressed as probabilities of contamination for forward ($<10^{-2}$) and back ($<10^{-6}$) contamination. The four industry teams contracted to do the concept studies (Ball Aerospace, Boeing, Lockheed Martin, and TRW) each came up with their own concept for mission segments starting with Earth-to-Mars cruise, Mars orbit, and lander EDL, then continuing through lander surface operations, ascent from Mars, orbit rendezvous, Mars-to-Earth cruise, and sample delivery to Earth. Dr. Mattingly compared key elements of the four concepts in each of these mission segments.

In 2002, a program decision was made that the cost for the mission as first conceived was too high for NASA's budget. To revisit the requirements, a MSR Science Steering Group was formed as a subset of the Mars Exploration Program Analysis Group (MEPAG). Also, the schedule for MSL launch slipped to 2009, pushing the first MSR mission to 2013. The result was a change to a "ground-breaking MSR" (GB MSR) that would not be mobile, rather than a MER-class roving sample collector. An arm would be used to collect samples around a lander having no surface mobility. A simple sample-context camera would be mounted on the arm to aid in sample collection. Material collected would be mixed in one container, versus the original concept of segmented samples in multiple containers. The revised project schedule for a 2013 launch allows for a "relaxed" development phase of 56 months. The sample would be returned in mid-2016. This replan cut the cost estimate from $1.6 billion to $0.9 billion. Dr. Mattingly reviewed the cost estimates developed by the source teams and the cross-checking of the estimates performed by Aerospace Corporation. and SAIC. A technology board for the GB MSR has been named, to provide the basis for technology planning and systems studies.

Dr. Mattingly said the biggest PP challenge for GB MSR is ensuring containment of anything returned to Earth that could have come from Mars (maintaining a less than one in a million probability of inadvertent release to Earth's biosphere). The second biggest challenge is to prevent a round trip of Earth microbes in the returned sample (maintaining a less than 1 percent probability of microbial contamination of the sample). These PP requirements set the goals for the concept studies and the GB MSR technology program. He described the current GB MSR reference design and the initial probabilistic risk assessments (PRAs) that have been done on implementing sample containment. The assumptions being made follow the path taken in the MSL PP planning, including the assumption of either COSPAR Category IVb or IVc status for the lander, depending on whether it goes to a Mars special region.

The PPAC members asked about a number of assumptions in the reference design and the PP implementation strategy, including whether the COSPAR IVa requirement might apply and the differences in system and subsystem cleaning under Category IVb or IVc to avoid a false positive from on-surface analysis or from Earth-derived contamination of the returned sample. Dr. Noonan summarized several comments under the heading of preventing any round-trip Earth microbes in the returned sample. Dr. Rummel noted that the PPAC might need to distinguish between cleanliness requirements related to the science objective and mission PP requirements. Dr. Mattingly discussed in detail the points in the sample return sequence where the chain of contact with the martian environment would be broken, except for the material enclosed as the sample. PPAC members asked questions about the Earth Return Vehicle (for the Mars-to-Earth cruise) and the Earth Entry Vehicle, which will carry the contained sample to its Earth landing. Members advocated the inclusion of a procedure blank (e.g., a sample chamber that would remain unexposed to the martian environment but otherwise the same as the chamber containing the sample) in the design. **Action Item:** Dr. Richard Orr asked to see the preliminary PRAs, if they could be provided. Other questions focused on the need for biobarriers between the lander body and the collection arm (particularly if the lander body is only clean to Category IVb) and between the Orbiting Sample and the Earth Return Vehicle. **Action Item:** Dr. Noonan noted that a compact disk (CD) containing electronic versions of the presentations would be prepared for distribution to the PPAC members.

Mars Returned Sample Handling Study

Dr. James Campbell, the study manager, described concepts being studied for a Mars sample receiving facility. He gave an overview of the study process, discussed the mid-term results, and described the schedule for the final reports, which will be put on a CD. Seven companies responded to the letter of interest solicitation (which was described at the May 2003 PPAC meeting). The three teams selected met in July 2003, during a Mars conference at the California Institute of Technology. Each team is led by a well-known architectural firm and supported by consultants with acknowledged expertise in their fields. The teams' studies are based on satisfying the NASA test protocols for physical and chemical characterization, life detection, and biohazard testing. Weekly telephone conferences and monthly meetings are being held with each team to discuss the test protocols, the draft Mars sample return protocol, and other issues. The sample receiving facility (SRF) is a concept and does not necessarily imply a single facility. Each facility concept covers physical/chemical processing and analytic tests, life detection testing, biohazard testing, and sample preservation for pristine curation. The teams have not yet put much effort into how the sample container would be opened. Perhaps 50 g would be used in the initial safety testing.

All three teams have developed their concepts to use one or more Biohazard Safety Level 4 (BSL-4) containment vessel housed within a clean room environment, rather than an entire BSL-4 facility. The three concepts had varying levels of robotics capability inside the containment vessel. Each team also presented a general approach for partnering with a university or other partners, to use facilities being considered for other biohazard isolation purposes. Dr. Campbell said that the teams were specifically tasked to design a NASA facility, and he did not know if they would have time to consider facility partnering approach in any detail, beyond these statements of a general approach.

Dr. Jonathan Richmond, a biosafety consultant and former director of the Office of Health and Safety, Centers for Disease Control and Prevention, discussed the adequacy of biosafety aspects of the SRF concepts. He began with three broad objectives for the SRF: maximum biocontainment to protect Earth's biosphere, clean room technology to ensure integrity of returned Mars samples, and providing a Planetary Protection Laboratory, rather than simply assuming a given BSL or clean room objective. For the biocontainment objective, he compared two biocontainment options. One is a class III biosafety containment (BSC) box, which can have laminar flow and HEPA filters, but with biocontainment. The other option is a BSL-4 suit lab. The three study teams used the biocontainment box approach.
For the clean room objective, he discussed mechanisms of filtration to remove Earth contamination from air in the biocontainment space. After summarizing features common to all three of the SRF concepts, Dr. Richmond noted there is an inherent tension between the relative air pressure requirement for isolaters (keep contamination out) versus class III BSCs (keep contained material in). Although all three concepts make some use of robotics, he has concerns about the extensive reliance on robotics in one of them.

During the question period, PPAC members asked about the committee's role in the SRF concept development process and the international issues in sample handling. Dr. Atlas suggested, and Dr. Richmond agreed, that partnering with a BSL-3 facility being constructed for other purposes might be counterproductive because of ongoing lawsuits over the way in which environmental impact statements were prepared for those facilities.

Dr. Carlton Allen, Astromaterials Curator at Johns Space Center, discussed scientific curation of returned samples. The scientific objective of sample curation is included in the Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth. It includes both prevention of contamination by terrestrial (Earth-origin) materials and maintenance of strict biological containment. According to the draft protocol, 90 percent of a returned martian sample goes into pristine curation until hazard testing in the SRF is completed. Depending on the results from this initial SRF testing, the sample in curation may be either (1) used only in further research conducted within the SRF, (2) distributed for research but only in biocontainment, or (3) distributed for research outside biocontainment. Dr. Allen described the general procedures for NASA sample curation. For samples returned from the Moon or other extraterrestrial sources where biohazard characterization is not an issue, the entire sample can be placed in pristine curation until one or more of the three research options is approved. Curation comprises initial characterization of new samples, preparation and allocation of samples for research and education, and pristine secure storage to support future research. To minimize environmental contamination of samples, they are maintained under class C flowing nitrogen at positive pressure or sealed in metal or Teflon® for transport. To minimize particle contamination, either a class 1,000 cleanroom is used with gloveboxes or a class 10 cleanroom without gloveboxes. For storage, the samples are in sealed containers with a nitrogen atmosphere and housed in a facility with multiple layers of physical security. Dr. Allen discussed the curation approach proposed in each of the three studies, with his assessment of the strengths and concerns in each approach.

James Campbell closed the presentations with a summary of the cost estimate for each SRF concept and recommendations for additional SRF studies. One SRF proposal includes the concept of a double-walled containment vessel, to provide an inner atmosphere over the sample at positive pressure to prevent contamination, surrounded by a containment layer at negative to provide biocontainment. This concept needs further proving, and a prototype may need to be built. Other issues that require further study arise with respect to the animal testing required by the draft protocol. Mr. Campbell suggested that further refinement of the draft test protocol would be helpful. In response to a PPAC question, he said that costs of monitoring and isolating SRF workers were not included in the mission studies. After the final reports are delivered at the end of February, he hopes to present the results to Orlando Figueroa. If NASA approval and funding support can be obtained, he would like to pursue the studies further.

<u>Solar System Exploration/Mars Program Status</u>

Orlando Figueroa, Director of the Solar System Exploration Division and Director of the Mars Exploration Program (MEP), briefed the PPAC on the status of work in his division and in the MEP. He covered the operating missions in each of the three categories of flagship, medium class, and small class missions. He noted the successful conclusion of the Galileo mission and Cassini's approach to Saturn and Titan. Significant progress has been made in defining science objectives for JIMO, the next flagship mission. The planetary science community has highlighted the importance of a Europa lander as a secondary objective of JIMO, and NASA will be looking at implications of incorporating a lander in the JIMO mission, including the PP issues. The plan for flagship missions beyond JIMO will call for one $3-4 billion class missions every 5 years or so, enabled by nuclear technology from the Prometheus Project. The science community will be engaged to contribute to the technology roadmaps for these missions to destinations such as Neptune. The technology will be grounded in the Project Prometheus investment, with JIMO as the first step.

Medium class missions are in the New Frontiers program. They will address high-priority mission concepts from the NRC decadal surveys. The first New Frontiers mission, New Horizons/Pluto-Kuiper Belt, has passed its critical design review. Some concern exists about launching radioisotope thermoelectric generators (RTGs) with an Atlas V launch vehicle, and work is needed to meet the National Environmental Policy Act (NEPA) launch approval requirements. A sample return mission to the Mars South Pole/Aiken

Basin received considerable attention in the Notices of Intent in response to the New Frontiers Announce of Opportunity (AO). Full proposals are due in February for the Phase A selections.

The small class of solar system exploration missions fall within the Discovery program. Genesis is doing well in collecting solar wind samples, which will return to Earth in 2004. Stardust successfully collected samples from comet Wild 2, and the accomplishments of the Stardust mission are large, although the news coverage has been overshadowed by the landing of Spirit on Mars. Planning for sample recovery, curation, and investigations are in progress for both Genesis and Stardust. Overall, the operational missions are doing well. However, each of the developmental missions, MESSENGER, DAWN, and Deep Impact, is having problems staying under the Discovery cost cap. Mr. Figueroa is establishing a Discovery Program Office at JPL to improve focus and discipline in the development phases of Discovery missions. The next Discovery AO, which will be released in February or March, will be under the auspices of this new program office.

In summarizing the Solar System Exploration activities, Mr. Figueroa said it has an abundance of valuable missions covering the current theme road maps. A new cycle of road mapping will begin this summer. The division continues to receive many competitive proposals in response to AOs and NASA Research Announcements (NRAs). In response to a question about the anticipated announcement of a new Presidential Initiative for human space exploration, Mr. Figueroa said it was unlikely to affect the division's strategies. Strategic planning in the Office of Space Science is guided by the competitive and peer review processes. In the theme road maps, sample return is a high priority for exploration of many bodies in the solar system. He anticipates an increasing emphasis on questions about life elsewhere in the universe.

With respect to the MEP, Mr. Figueroa gave an abbreviated update because the PPAC had heard about many of the missions on the first day of its meeting. The orbiter missions to Mars have been important in preparing for the MER mission and providing a conduit for communications from surface missions. He noted the value of this communications link in providing the surprising data about the martian atmosphere during Spirit's EDL. Spirit's landing and the preparations to roll off its lander have been front-page news in over 200 newspapers worldwide.

Mr. Figueroa asked the PPAC for members' questions on program aspects of missions in development. Dr. Noonan noted that the PPAC had been discussing the PP challenges of MSL and was finding that the same kinds of issues arose for MSR mission concepts. Mr. Figueroa asked for the advice of the PPAC on MSL, particularly with respect to planetary protection issues and their implications for MSL's analytical instrumentation. Within the next two months, the MSL program needs to know what it can and cannot undertake. At present the planetary protection requirements and the analytical instrumentation to meet MSL science objectives are together creating a severe challenge to the mission's cost cap. Dr. Noonan replied that the committee would be continuing its discussions on MSL issues and would try to provide advice and comment useful to him.

Mr. Figueroa agreed that MSL paves the way for future surface missions on Mars and elsewhere. In the four exploration pathways for the Next Decade of Mars Exploration, MSR and next-generation mobile surface laboratory missions are prominent in the front to middle portion of each pathway. MRO and MSL are capability developers for these missions, as well as gathering the information needed to select among the pathways. For example, MSL should be viewed as a gauge for next-generation mobile laboratories. With respect to MSR, he is comfortable with the sample collection and return concepts but is not yet comfortable with the concepts for the SRF. The PPAC's comments and advice on those areas will be important to help him complete the picture for a sample return mission. Mr. Figueroa does not see the Mars program being diverted by a new presidential initiative, if there is one. The third objective of the MEP, to prepare for eventual human exploration of Mars might be amplified. Planned missions might be augmented, or new missions might be added. In his view, all the work of the science community in helping NASA to develop a strategy for the next decade of Mars exploration has paid off. There could be a launch of a MSR as early as 2013.

In response to a question from Dr. Zoloth on how the ISS and Shuttle fit with the plans he had described, Mr. Figueroa said that those programs are outside the Space Science Exploration Division and the MEP.

Dr. Noonan noted that the MSL team had described the challenge of balancing conservatism on planetary protection with cost constraints. If MSL is a pathfinding mission for missions to follow, she asked, why should the MSL project be forced to assume what could be seen as larger, programmatic investments affecting a number of missions? Mr. Figueroa replied that NASA may be forced to look at it in the way Dr. Noonan suggested. However, he expressed doubt that the entire trade space for meeting the various constraints on the MSL had been fully explored yet. He sees the debate thus far as being limited to Viking-era concepts (of planetary protection approaches) and welcomed the PPAC's comments on whether it is reasonable to continue that approach or examine alternatives. The same reasoning applies to MSL instrumentation, which can be viewed as an investment in technology for the MSL instruments, but is also pathfinding for future missions. The cost risk to the MSL mission is currently around $100 million, he said, and it would be important to lessen that risk, if feasible.

Dr. Noonan congratulated Mr. Figueroa and the division on the recent successes of both Stardust and the Spirit rover. She noted that the sense of the committee is that ambitious missions are being planned, and some hard thinking is needed about the trades involved. She agreed that the SRF will require further study, to answer some of the unanswered questions. What is needed is more in the line of next steps, not a redirection from what has been done in the current set of mission studies. Mr. Figueroa said that he would welcome the PPAC's thoughts on that particular area, as well as any reflections on the larger approach to planetary protection and how to make advances in the technology needed. Dr. Rummel added that some of the specific issues related to the SRF are being addressed in part by activities within the Mars technology program. Dr. Noonan said the PPAC appreciated the opportunity to ask its questions at a very early phase of mission planning. Dr. Levy suggested that planetary protection should be viewed as a NASA (programmatic) endeavor that needs attention beyond the work for specific missions. Within the current approach, he sees limited opportunity for NASA to explore options or build facilities with multiple mission applicability. Mr. Figueroa accepted that as a fair view, particularly as the budget line for PP technology had been deleted during budget cutting. Something like that would be an example of what he meant by a different PP strategy than the current one.

Committee Discussion

Immediately following the lunch break, the PPAC continued its discussion of PP issues for Mars missions. Dr. Carle Pieters asked about measurements one could make on the surface of Mars that might simplify the problems of sample return. This led to a discussion of the effects of ambient ultraviolet irradiation at the martian surface on organic compounds and reasonable interpretations of the Viking measurements, which failed to detect the level of organic compounds that would have been present on the surface just from meteorite remnants. Dr. John Kerridge noted that the capability to analyze samples for organic constituents, which had originally been part of the plan for the MERs, had been deleted for budgetary reasons.

Stardust Status and Plans

Thomas Duxbury, the Stardust Project Manager, briefed the PPAC on the current status and plans for the Stardust mission. Stardust is a Discovery project that was launched after the Mars Polar Lander failure in 1998. The project has done some extra work to mitigate mission risks within the project budget. The Stardust spacecraft flew within 205 km of the nucleus of comet Wild 2 after being in flight for five years. The expectation was that vapor jets from solar heating of the nucleus would be mixed, but the collectors traversed five distinct jets. The particles collected are now on the return flight to Earth. When the sample reaches Earth in January 2006, it will go to the curation facility at Johnson Space Center (JSC). The return vehicle has a heat shield similar in shape to a small Mercury capsule. A drogue shoot will slow the descent. The U.S. Space Command will be tracking the vehicle during entry and descent. Mr. Duxbury detailed the EDL error mitigation steps taken or planned. The entry angle error (within three standard deviations) is less than 0.08°. Five of the trajectory correction maneuvers in the return flight plan have been cancelled because they will not be needed. Return maneuvers have been tested with the spacecraft during the flight out to Wild 2. Because the mission teams for Genesis and Stardust overlap, the Genesis sample return will be a preparatory run for the Stardust return.

Cassini/Huygens Mission Status and Planning

Robert T. Mitchell, Cassini Program Manager, briefed the PPAC on the Cassini mission, including the Huygens probe it is carrying to release for impact on Titan. Cassini, which is 7 meters in length from the low-gain antenna to the bottom of the engine, has collected some data during its flight toward Saturn, including pictures of Jupiter and Saturn. Mr. Mitchell reviewed the scientific and navigation instruments on board both Cassini and the Huygens probe, which is tucked up under it at present. The three RTGs on board provide power for the spacecraft. Mr. Mitchell described the trajectory correction maneuvers that would be made in preparation for and during Saturn orbit insertion and particle collection. He also discussed the link receiver problem that has required changing the original trajectory planned for the Huygens probe. The surface imager on Huygens is expected to provide data until impact on the Titan surface. After the probe-related activities are completed, Cassini is funded for a four-year tour of orbiting around Saturn. Cassini's primary science mission has officially started.

In response to Dr. Noonan's question about the fate of Cassini after its mission life, Mr. Mitchell said that has not yet been decided. It could remain in orbit around Saturn for an indefinite period. He described the major activities under way to prepare for the active observation period during the Saturn tour. The most labor-intensive preparations are involved in planning the science observation sequence because all instruments are fixed to the spacecraft body and pointed by moving the spacecraft.

Genesis Update and Small Sample Return Comparison

Because of time constraints on the agenda, the briefing slides on Genesis were distributed to the PPAC members without oral presentation or discussion. The mission will be discussed at the next meeting.

Preparatory Discussion: Planetary Protection for the Outer Planets

Dr. Rummel reviewed the current PP plan for the outer planets, as stated in NASA Policy Directive (NPD) 8020.7F. The current policy, which agrees with the COSPAR policy, focuses on preserving the scientific value of the planets. Missions cannot jeopardize the conduct of scientific investigations of possible extraterrestrial life forms, precursors, or remnants. Also, the Earth must be protected. With respect to the importance of maintaining the presumption of ignorance about extraterrestrial life, Dr. Rummel noted that, despite several centuries of exploring the oceans, the existence of deep-sea thermal vents was unknown and unsuspected until 1977. That was seven months after Viking landed on Mars. In 2000, the SSB released a report on *Preventing the Forward Contamination of Europa*. This report recommended that, for every mission to Europa, the probability of contaminating a possible europan ocean with a viable terrestrial organism at any time in the future should be less than 10^{-4} per mission. The study committee concluded that this limit can be achieved with current sterilization techniques, if the hardware allows those techniques to be used. With respect to assaying bioburden, the current culture assay method should be supplemented by a means of assaying extremophiles. The report included a sample calculation of the probability of Europa contamination. In this context, Dr. Rummel discussed where bioburden reduction may be necessary on JIMO and a europan lander. Likely PP impositions on JIMO include reduction of spacecraft biological contamination, constraints on spacecraft operating procedures (e.g., failure-tolerant orbits), inventorying and restricting organic components on the spacecraft, documenting spacecraft trajectories, and archiving of spacecraft materials. Restrictions on handling of returned samples would apply to potential future missions with sample return.

JIMO Mission Status and Plans

Sarah Gavit, JIMO Project Engineer, briefed the PPAC on JIMO mission status and PP planning. The two overarching objectives for JIMO are to: (1) develop a nuclear reactor-powered spacecraft and show it can be processed safely, launched safely, and operated safely and reliably in deep space; and (2) explore the three icy moons of Jupiter and return science data that meet the highest scientific goals as set forth in the Decadal Survey. The JIMO Science Definition Team (SDT) developed four science discipline goals (goals in the areas of surface geology and composition, interior science, astrobiology, and Jupiter system science) and the objectives under each goal. From this compilation of goals and objectives, the SDT derived three themes that cut across the discipline goals: oceans and active internal processes, astrobiology (volatiles, organics, and chemical processes), and jovian system interaction processes (satellites, atmospheres, surfaces, and interiors).

JIMO will launch not earlier than 2011, but more likely in 2012. The spacecraft will weigh 26,000 kg at launch. Hydrazine fuel will be used for ion propulsion. The transit time from Earth to Jupiter will be 5 to 8 years, depending on specifics of the propulsion system and flight path, with 4 to 6 years of science observation time. JIMO will orbit Callisto for at least 60 days, Ganymede for at least 120 days, and Europa for at least 30 days. At end-of-mission, JIMO will be moved to a stable quarantine orbit for planetary protection considerations. The orbiting time around Europa is constrained by the high radiation environment (from Jupiter) around Europa. During orbiting maneuvers, most of the orbits are unstable and could pose a problem of impact on the moon being orbited, if propulsion were lost for too long at the wrong time. After answering PPAC questions on the basic mission plan, Ms. Gavit described the trade options and technologies under consideration for the major subsystems of the spacecraft. The ion thrusters will not have flown in space before being used in JIMO. The science capability parameters in the current spacecraft concept include 1,500 kg for the science package, 10 kW of power to the payload when not thrusting, 3 kW to the payload during thrust, data rates greater than 10 Mbps, and full hemisphere fields of view for bus-mounted, scan platform-mounted, and turntable-mounted instruments.

The JIMO project science office reports to the Solar System Exploration Division, while the JIMO Project Office, under John Casani as Project Manager, reports to Al Newhouse in the Project Prometheus Program Office, within the Office of Space Science. The JIMO SDT is preparing its final report now, for delivery in February. The JIMO project is now in phase A. A government study team is working on the space system, launch vehicle, and ground system for JIMO. Three industry partners are competing on spacecraft design. Substantial investments are being made in the technologies needed for the nuclear reactor, power system, ion thrusters, and telecommunications. The mission system design review is scheduled for early 2005, at which time the project will move into phase B. Phase B is scheduled for about 2 years, ending with the project preliminary design review.

Planetary Protection Approach and Issues for JIMO/Europa

Charles Kohlhase presented the JIMO project's approach to planetary protection, with particular emphasis on protecting Europa from forward contamination during orbit around it. The presentation did not address PP issues of a Europa lander because that option has not been studied yet. Because of the low thrust during interplanetary travel, there is no planetary contamination threat for five to seven years after JIMO's launch. Once in orbit around a jovian moon, however, the near-polar, highly elliptical orbits needed for the science objectives will be unstable. This aspect of the mission increases the probability that a loss of thrust at the wrong time, for a sufficient length of time, could cause an unplanned crash on the body being orbited. (An unstable orbit is one that decays to an impact consequence in weeks to months; a stable orbit is one that lasts for a century or longer.)

The SSB report on preventing the forward contamination of Europa recommended a requirement that the probability of contaminating a europan ocean with a viable terrestrial organism (P_c) *at any time in the future* should be less than 10^{-4} per mission. The COSPAR documents on PP from around 2002 retain the ceiling value for P_c of 10^{-4} per mission, but they do not include the "at any time in the future" condition. The JIMO team has worked with these statements as the benchmark for PP planning. One issue, however, is the duration over which the P_c limitation extends. If it is 10^7 to 10^8 years, which is the interpretation of "at any time in the future" used in the SSB report, then a probabilistic risk analysis to verify that the PP requirement will be met becomes extremely difficult. The Project Prometheus/JIMO team is proposing that the NASA PP Officer limit the period for which the 10^{-4} ceiling on P_c applies to the first 100 years after mission launch. Mr. Kohlhase's argument for this interpretation was that the probability estimates do not have much significance for periods substantially longer than a century. Next, he explained the probability relationships he is using to calculate estimates of P_c. He used the factors in the equations to illustrate the general approach being taken to demonstrate compliance with a 10^{-4} ceiling on P_c as the PP requirement JIMO must meet. In response to questions from the PPAC, he discussed the plan to include sufficient reliability, such as redundancy in the spacecraft's systems, to make JIMO single-fault tolerant once Jupiter science starts (after interplanetary travel). He also described the approach for estimating survival of radiation-resistant bioburden. Other issues discussed included the appropriate assumption for the time required for the frozen surface of a europan ocean to exchange with the warmer liquid ocean underneath and whether RTGs would melt through the ice to the liquid ocean. PPAC members asked Dr. Rummel about the interpretation of the COSPAR statements and discussed the trades among system and subsystem complexity, mission cost, and PP consequences. Mr. Kohlhase listed the next steps in the PP planning for JIMO, which include (1) getting the PP Officer's response to the approach, the suggested PP requirement, and other assumptions in the analysis, (2) working out the most effective approach to meeting the PP requirement, and (3) resolving the major issues as soon as possible.

Committee Discussion

The PPAC discussed the request from Brian Muirhead for advice on the ceiling probability that the MSL PP plan should assume for an off-nominal landing. The PPAC discussed approaches for deriving this ceiling probability, including whether and how the "heritage" probabilities from the COSPAR deliberations prior to Viking still can be used. Dr. Rummel pointed out that having a feasible means of terminal heat sterilization will be important for other missions beyond MSL, such as MSR missions. Thus, there is value in proceeding now (for MSL) with developing a technique that is more appropriate than the Viking sterilization method. After further discussions and suggestions from PPAC members, Dr. Noonan said that the PPAC should take the time to do this task correctly and not try to make a decision at this meeting. She added that the PPAC will need to examine the broader issues of where the costs and risks should be taken: whether in a single project such as MSL or as part of a broader NASA program to address PP science and technology needed for multiple planned and potential missions.

Issues in Spacecraft Sterilization

Karen Buxbaum of the Biotechnology and Planetary Protection Group at JPL discussed issues in spacecraft sterilization technology and procedures. She reviewed the history of NRC, COSPAR, and NASA deliberations and positions on sterilization, leading up to a gap between early sterilization policies (stemming from the Viking era) and the major revision of NASA PP policy in 1981. As part of this history, she commented on a number of often-repeated statements that are not entirely accurate or leave out important points (legends and myths about spacecraft sterilization). Although it is true that sterilization requirements added to the difficulty and cost of the Viking mission, reconstructing what those requirements actually cost is very difficult. She agreed that modern spacecraft are probably incompatible with system-level DHMR as currently designed, but she believes a committed program for flight-qualifying materials and parts after exposure to DHMR conditions could make system DHMR feasible. She noted that more than 60 percent of the MER rover surface area and more than 90 percent of other MER bioburden-accountable surface area was treated with DHMR. Also, 48 percent of the line items on the MER planetary protection equipment list were treated with DHMR. Although it may be easier in some respect to use DHMR for just the part of a system that will physically contact a Mars special region, partial DHMR raises other complexities (such as the off-nominal landing issue for MSL). Placing a spacecraft in a quarantine orbit at end-of-mission or having a safe final disposition plan (as with Galileo) does not remove the need to be within PP limits throughout the operational mission. She also disagreed with the blanket statement that the orbital lifetime approach to meeting PP requirements for a Mars orbiter is always preferable, from a project's perspective, to meeting the bioburden requirement with system-level DHMR.

Ms. Buxbaum described some of the pressures on PP technology development in general—and spacecraft sterilization in particular—for a project, given the new era of mission cost caps and short project life cycles. Technical complexities in using system-level DHMR arise from changes in materials, parts, and packaging, as well as from the use of heritage or commercial-off-the-shelf (COTS) hardware to reduce costs. With respect to potential methods of sterilization, there are dozens of modalities in use in industries ranging from food processing to medicine to semiconductors. However, NASA has just one approved standardized sterilization modality for PP (DHMR) and just one in the development and testing pipeline leading to standardization and approval (hydrogen peroxide vapor). Three or four other modalities have been proposed for further study, on the basis of preliminary trade studies. New technical challenges for spacecraft sterilization include when to sterilize prior to launch versus in flight, which extremophiles are important to consider, and whether non-sporeformers are an issue for PP, requiring new PP guidelines and methodologies.

Ms. Buxbaum addressed four sterilization-related questions raised at the May 2003 PPAC meeting. First, she listed some of the organisms that experience far less than four orders of magnitude (10^4) reduction when exposed to NASA's standard DHMR method and others that survive high radiation exposures. It is clear, she said, that there are organisms in the Earth environment that are tougher than our electronics, so shielding the electronics (from heat or radiation) will also shield the resistant organisms. In response to a PPAC question, a member of Ms. Buxbaum's team said that the extremophiles she had listed all require substantial levels of nutrients other than water to multiply. PPAC members discussed the possibility that other bioburden organisms (e.g., chemobacteria, other autotrophs) could propagate in a moist environment with limited or no organic nutrient supply. Ms. Buxbaum added that the current NASA bioburden requirements require counting (enumerating) numbers of viable organisms but do not require identifying or characterizing those that survive. She agreed that moving forward with improved PP procedures may require knowing what is present, as well as how many. On the second PPAC question of whether electronics are more resistant to radiation (e.g., gamma radiation, high energy particles) than to dry heat, she said that many electronic *components* are very heat-tolerant, but many electronic *assemblies* are not. The electronic assemblies are probably radiation tolerant, but not all the components are radiation tolerant. The third PPAC question asked if ultraviolet (UV) radiation could be used for sterilization instead of heat. Ms. Buxbaum said that UV radiation can only be used to sterilize surfaces, and shadowing is a problem for UV methods. The fourth PPAC question asked about options for different time–temperature combinations for DHMR and other alternative methods. Ms. Buxbaum said that higher temperatures and shorter times are an attractive option for designers at the assembly and sub-assembly levels. However, for system-level DHMR, use of higher temperatures is limited by the least heat-tolerant subsystem. In general, she agreed that alternative methods are worth consideration, but options for bulk sterilization are limited to a few modalities: heat or radiation, at this time.

Associated R&D challenges for spacecraft sterilization include cleaning prior to sterilization, maintaining cleanliness, verification assays and effective, reproducible sampling methods, and maintaining sterility with biobarriers. To return to system-level DHMR as a PP option, R&D is needed on (1) sensor and system electronics that are DHMR-compatible, and (2) system test methodologies to assess reliably the lifetime performance of systems subjected to DHMR. Also needed are cost-effective system DHMR facilities, perhaps at multiple locations. Ms. Buxbaum listed the major issues with using various sterilization modalities for system-level treatment of, for example, a MER or a Europa lander. The evolving understanding of environments on Mars and other bodies such as Europa has increased PP requirements to prevent forward contamination of an aqueous environment. The technology needed to meet this challenge includes alternative standardized sterilization modalities (e.g., hydrogen peroxide vapor), advanced assays (addressing both extremophiles and nonculturable organisms), improved cleaning methods, sterilization techniques for today's electronics, and system/assembly architectures that facilitate sterilization. A particular problem is that there is no current verification assay for bulk contamination in materials. Basic biological research on organism survivability in high-radiation environments is also needed. Ms. Buxbaum described the current program for PP technologies, which she characterized as "lean," within the Mars Technology Program. There is no PP technology program for non-Mars missions. Ms. Buxbaum gave a partial list of research topics to address PP issues and technology needs.

During the ensuing discussion, Dr. Noonan asked about a visual inspection approach to counting or identifying microbes to establish ground truth on bioburden, rather than relying on assays, each of which has selection biases. In response, Roger Kern from the JPL Biotechnology and Planetary Protection Group described technical issues in visualizing organisms directly on surfaces. Use of swabbing to remove them raises selection/bias issues as well. Dr. Atlas asked about the status of investigations into use of biochemical assays. Issues with biochemical essays, such as background interferences, and the potential for fluorescent methods of visualization on opaque surfaces were discussed. The PPAC members and Dr. Rummel discussed difficulties with testing proxy materials or items, rather than actual spacecraft components or assemblies.

In response to Dr. Noonan's question about the level of investment in PP R&D, Ms. Buxbaum said there was no single budgetary line item for it. Her program at JPL is working on compiling data on the level of investments during the recent past. Some partial work on developing a rapid spore assay and new work on organic cleanliness for MSL total about $700,000 per year. The program is trying to identify funding for work on biobarriers, which would be applicable to the Phoenix project. The only current work on sterilization is $1.5 million for characterizing the hydrogen peroxide vapor method sufficiently to move in along in the lengthy and expensive process required for a NASA standard procedure. Ms. Buxbaum estimated that the total level of effort in PP R&D at JPL was less than $5 million per year. She discussed with Dr. Cavanaugh the difficulties in trying to pursue R&D on assay methods for nonculturable or anaerobic spores, given the current assay and bioburden rules that projects must address. Dr. Atlas generalized the issue as one of updating PP standards to reflect new science about the survival of organisms under the conditions of space flight. Dr. Rummel said that mission programs generally address evolving science issues in requirements only when they are told an issue must be addressed before the mission can fly. JPL has been investing some of its program funds in these areas on its own and is trying to win NASA funding support to do more. Dr. Noonan said that this kind of situation requires a cross-mission technology R&D program in NASA for PP. The members discussed actions the PPAC could take to force NASA attention to the need for such a program. They agreed that such a program should include technologies to reduce bioburden, including sterilization methods and associated issues, and technologies for identification and characterization of bioburden, including organisms of concern not identified by the current NASA standard assay.

Planetary Protection at JPL

Ms. Buxbaum described the history and status of PP support activities at JPL. PP responsibilities are part of the JPL prime contract with NASA and are explicitly called out in JPL flight project practices. PP is an element in JPL's standard work breakdown structure for flight projects and is taught as a section in the training programs for project managers, project element managers, and cognizant engineers. Organizationally, JPL's PP support is centered within the Engineering and Science Directorate as the Biotechnology and Planetary Protection Group. A management decision in 1998 reorganized activities to provide an explicit focus on PP, and the group was formed to consolidate JPL expertise in PP. Since 1998, there has been parallel development of workforce and infrastructure, but also a steady increase in the quantity and difficulty of PP work and related challenges. At JPL, the Solar System Exploration Program Directorate and the Mars Program Office support planetary protection activities with financial and technical resources and have offices with PP roles and responsibilities. The JIMO Program Office and New Frontiers Program Office also have PP responsibilities. The Biotechnology and Planetary Protection Group does R&D and strategic planning, as well as direct project support. PP facilities at JPL include the biomolecule detection lab, general microbiology lab, PP flight support lab, and an extreme environments biology lab. A PP Steering Committee is currently engaged in strategic planning for a PP technology plan to propose to NASA. This activity is also looking at areas where JPL should be making its own internal investments in PP R&D.

Dr. Noonan asked when the strategic plan for PP R&D will be ready. Ms. Buxbaum said the commitment is to deliver a product to the JPL Chief Scientist this year. The plan will influence JPL's internal research and technology development (R&TD) budget for fiscal year (FY) 2005. The hope is that NASA headquarters will find elements of the strategic plan worth supporting, perhaps as part of a headquarters-led technology development program in PP for solar system exploration.

Wrap-up Discussion and Close

The PPAC members and guests continued the earlier discussion of how a PPAC recommendation could be worded to express the need for a PP technology program broader than the efforts to support any single mission. Dr. Noonan said she would draft a letter to Dr. Weiler and circulate it to the PPAC members for comment, revision, and eventual approval. She reminded the members that they would be contacted to determine availability for another meeting based on upcoming events. Dr. Noonan adjourned the meeting at 5:40 p.m.

PLANETARY PROTECTION ADVISORY COMMITTEE (PPAC)
Conference Room 167, Jet Propulsion Laboratory, Pasadena, California
January 12–13, 2004

AGENDA

Day 1—Monday, 12 January 2004

8:30am	Welcome and Meeting Overview	Norine Noonan/John Rummel
8:35am	Center's Welcome	Thomas Prince, JPL
8:45am	Planetary Protection Update	J. Rummel
9:00am	MER Mission Status, Results, and Planning (inc. Press Conference)	JPL
9:45am	Planetary Protection Update (cont.)	J. Rummel
10:15am	Break	
10:30am	MRO Status and Planning	Jim Graf, JPL
11:15am	MGS Status and Results	Arden Albee, Caltech
11:45am	Mars Odyssey Status and Results	Jeff Plaut, JPL
12:15pm	Lunch	
1:15pm	Committee Discussion, Future Mars Requirements/Advice	J. Rummel
1:45pm	Phoenix Status and Planning	Barry Goldstein, JPL/Peter Smith, U. of AZ
2:30pm	MSL Science Planning	Frank Palluconi, JPL
2:55pm	MSL Project Status	Mike Sander, JPL
3:20pm	Break	
3:30pm	MSL Planetary Protection Study & Discussion	Brian Muirhead, JPL Mike Sander
4:30pm	Committee Discussion, Mars Requirements	Norine Noonan
5:15pm	Adjourn	
7:00pm	Committee Dinner	Café Santorini

PLANETARY PROTECTION ADVISORY COMMITTEE (PPAC)
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AGENDA (continued)

Day 2—Tuesday, 13 January

8:30am	CAIB Report and Contour Mishap Report	J. Rummel
9:00am	Committee Discussion, MSL/MSR Requirements	N. Noonan/J. Rummel
9:30am	Mars Sample Return Mission Concepts	Richard Mattingly, JPL
10:15am	Break	
10:25am	Mars Returned Sample Handling Study	James Campbell, JPL Carlton Allen, JSC Jonathan Richmond, Consultant
11:15am	Solar System Exploration/Mars Program Status	Orlando Figueroa (
11:45am	Cassini/Huygens Mission Status and Planning	Robert Mitchell, JPL
12:15pm	Working Lunch/Committee Discussion	
1:00pm	Stardust Status/Plans	Tom Duxbury, JPL
1:30pm	Genesis Update and Small Sample Return Comparison	J. Rummel
1:45pm	Preparatory Discussion: PP Requirements for the Outer Planets	J. Rummel
2:00pm	JIMO Mission Status/Plans	Sarah Gavit, Charles Kohlhase, JPL
3:00pm	Break	
3:15pm	Committee Discussion, Outer Planets Requirements	N. Noonan
3:45pm	Planetary Protection at JPL	Karen Buxbaum, JPL
4:15pm	Issues in Spacecraft Sterilization	Karen Buxbaum
4:45pm	Committee Discussion and Planning	N. Noonan
5:00pm	Adjourn	

PLANETARY PROTECTION ADVISORY COMMITTEE (PPAC)

Individual Members:

Dr. Norine E. Noonan, Chair
College of Charleston

Dr. John Rummel, Executive Secretary
NASA Headquarters

Dr. Ronald M. Atlas
University of Louisville

Dr. Colleen M. Cavanaugh
Harvard University

Dr. Carolyn S. Griner
Booz Allen Hamilton, Inc..

Dr. Debra L. Hunt
Duke University

Dr. John F. Kerridge

Mr. Alan Ladwig
Zero Gravity Corporation

Dr. Debra G. B. Leonard
University of Pennsylvania

Dr. Eugene H. Levy
Rice University

Dr. Carle M. Pieters
Brown University

Dr. Susanna Hornig Priest
Texas A&M University

Dr. George S. Robinson, III
Robinson & Associates Law Offices, P.C..

Dr. Diana Wall
Colorado State University

Dr. Laurie Zoloth
Northwestern University

Representative Members:

Dr. Michael H. Carr
U.S. Geological Survey

Dr. Paul Gilman
U.S. Environmental Protection Agency

Dr. David Klein
NIAID, National Institutes of Health

Dr. Richard Orr
U.S. Department of Agriculture; National Invasive Species Council

Dr. Robert A. Wharton
National Science Foundation

International Representatives:

Dr. Alain Berinstain
Space Exploration Program, Canadian Space Agency

Dr. Andrew J. Parfitt
CSIRO Australia Telescope National Facility

Dr. Michel Viso
Centre National d’Etudes Spatiales (CNES)

Professor Akira Fujiwara
ISAS

Dr. Gerhard Schwehm
ESA/ESTEC

PLANETARY PROTECTION ADVISORY COMMITTEE (PPAC)
Jet Propulsion Laboratory
Pasadena, California
January 12–13, 2004

MEETING ATTENDEES

Committee Members:

Noonan, Norine (Chair)	College of Charleston
Atlas, Ronald	University of Louisville
Cavanaugh, Colleen	Harvard University
Hunt, Debra	Duke University
Kerridge, John	Univ. of California, San Diego
Ladwig, Alan	Zero Gravity Corporation
Leonard, Debra	University of Pennsylvania
Levy, Eugene	Rice University
Pieters, Carle	Brown University
Priest, Susanna	Texas A&M University
Rummel, John D. (Executive Secretary)	NASA Headquarters
Zoloth, Laurie	Northwestern University

Representative Members:

Orr, Richard (*Agency Representative*)	U.S. Department of Agriculture; National Invasive Species Council

NASA Attendees:

Allen, Carlton	Johnson Space Center
Beaudet, Robert	JPL/ University of Southern California
Beaty, David	Mars Program Office
Bergstrom, Sheryl	Jet Propulsion Laboratory (JPL)
Beversburg, Stephen	JPL
Buxbaum, Karen	JPL
Campbell, James	JPL
Chen, Fei	JPL
Chen, Gurshig	JPL
Chung, Shirley	JPL
Cutts, Jim	JPL
Eisen, Howard	JPL
Figueroa, Orlando	NASA Headquarters (*by telephone*)
Gavit, Sarah	JPL
Gershman, Bob	JPL
Kazan, Gayann	JPL
Kempf, Mike	JPL
Kern, Roger	JPL
Kirschner, Larry	JPL
Kohlhase, Charles	JPL
Koukol, Robert	JPL
Krabach, Timothy	JPL
Mattingly, Richard	JPL
McBride, Karen	NASA Headquarters
Morales, Fabian	JPL
Muirhead, Brian	JPL
Murrill, Mary Beth	JPL
Newlin, Laura	JPL

NASA Attendee, continued:

Norris, Marian	NASA Headquarters
Pappanastassiou, Dmitri	JPL
Palluconi, Frank	JPL
Plaut, Jeffrey	JPL
Prince, Tom	JPL
Salinas, Yuki	JPL
Sander, Michael	JPL
Schubert, Wayne	JPL
Seidel, David	JPL

Other Attendees

Albee, Arden	California Institute of Technology
Braun, Robert	Georgia Institute of Technology
Christensen, Marvin	Lockheed Martin
Edgett, Larry	Spectrum Astro
Kauffman, Wayne	Spectrum Astro
Lewin, Lynn	BATC
Purdy, William	Ball Aerospace
Redmond, Jonathan	Jonathan Redmond & Associates
Russell, Eve	Dartmouth College
Stabekis, Pericles	Windermere

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Presentation Slides Distributed in Hard Copy

1) Laura Newlin et al., JPL. *Mars Exploration Rover: Planetary Protection Compliance Status Update*.
2) Jim Graf and Kirk Breitenbach. *Mars Reconnaissance Orbiter (MRO) Mission: Overview and Planetary Protection Status*.
3) Arden Albee, Project Scientist, MGS. *Mission Extraordinary—MGS Results and Status*.
4) Jeffrey J. Plaut, JPL. *The Mars Odyssey Science Mission*.
5) Peter Smith and Barry Goldstein. *Phoenix Project Overview*.
6) Frank Palluconi. *Mars Science Laboratory: MSL Science*.
7) Mike Sander. *Mars Science Laboratory: Mission Overview*.
8) Brian Muirhead. *Mars Science Laboratory: Planetary Protection Categorization Proposal Development Plan*.
9) Richard Mattingly. *Mars Sample Return (MSR) Status of Mission Studies*.
10) James Campbell. *Concepts for a Mars Sample Receiving Facility*.
11) Robert T. Mitchell, Cassini Program Manager. *Cassini/Huygens Mission: Status and Planning*.
12) Sarah Gavit. *JIMO Project Overview*.
13) Karen Buxbaum, Biotechnology and Planetary Protection Group, JPL. *Issues in Spacecraft Sterilization*.
14) Karen Buxbaum, Biotechnology and Planetary Protection Group, JPL. *Planetary Protection at JPL*.

Other Materials Distributed at the Meeting

1) *JPL Biotechnology and Planetary Protection Group. Capabilities and Activities.*