NASA ADVISORY COUNCIL

Planetary Protection Subcommittee

December 8-9, 2015

NASA Headquarters
Washington, D.C.

MEETING MINUTES

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Robert Lindberg, Chair

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Amy Kaminski, Executive Secretary

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Introduction

NASA Advisory Council (NAC) Planetary Protection Subcommittee (PPS) Chair, Dr. Robert Lindberg, opened the meeting. The Executive Secretary of the PPS, Dr. Amy Kaminski, made preparatory and logistical announcements. Introductions were made around the room.

Words from the Chair

Dr. Lindberg welcomed members to the meeting, and disclosed for purposes of transparency that he had recently taken a new position that has some relevance to planetary protection (PP), as Vice President for Orbital and Return Systems for Moon Express, a commercial entity that will be pursuing exploration and mining on the Moon. He noted that lunar missions might constitute future areas of recusal for him. The present meeting, however, would be focused primarily on Mars, the Mars Science Laboratory (MSL) Curiosity rover and the Mars 2020 rover in particular, the latter of which is being designed to possess the ability to cache samples in anticipation of a future sample return. Dr. Lindberg noted that this would be the first meeting in the era of confirmation of "Water on Mars," as there is now convincing evidence that recurring slope lineae (RSL), which have been imaged and analyzed over several seasons' duration on the Mars surface, are in fact the result of liquid brine.

Discussion with the Science Mission Directorate Associate Administrator

Dr. John Grunsfeld, Associate Administrator of the Science Mission Directorate (SMD), welcomed members of the PPS to NASA Headquarters, acknowledging the importance of PP as NASA science reaches a convergence of numerous lines of inquiry that are yielding data about habitable environments, and the nature of icy bodies in the solar system. Research may be on the verge of answering fundamental questions about life in the universe. PP is at the heart of this convergence as missions explore destinations that may harbor habitable environments. As a consequence, it is recognized that one must be able to rule out false positives on the other bodies in the solar system; e.g., Mars, should evidence of life actually be found on that planet.

MSL's exploration of Gale Crater has borne out orbital data on the presence of sedimentary rock, and ground truth has been verified as to the watery origin of these geological features. Recently, orbital images have revealed dark streaks that suggest the existence of "special regions," as defined by planetary protection (PP) protocol, in Gale Crater; this is a fascinating and important topic from a PP perspective. The Rover Environmental Monitoring Station (REMS) instrument on the Curiosity rover has measured a local relative humidity as high as 70%. Potentially, that humidity can cause certain hydrated minerals to release liquid water. A pressing question is whether the MSL team must work much harder to avoid special regions, and how the issue can be accommodated in terms of real-time operations. An analogous situation is encountered routinely in human space flight operations, such as dealing with ammonia leaks during an extravehicular activity (EVA); such go/no-go discussions are common. Mission management teams are created to treat these potential issues, and this construct can easily be used as a model for Mars surface operations. In the operations sector of mission management, there are now clear requirements that PP considerations be monitored during real-time mission operations. The rover's traverse path must be cleared from a PP perspective. If there is a potential special region in the path, the matter is kicked up the hierarchy, where MSL's Science Operations Working Group Chair makes the clear/not clear and go/no-go determination. Criteria have been developed for use by the Chair in this decision-making process, and these criteria are now documented in a checklist.

The next question is how a mission can investigate something like an RSL from a PP perspective, which requires a mission operations protocol for decision-making. Dr. Grunsfeld reported having directed such a protocol to be developed for operations on the Mars surface. The protocol will address questions such as: What is the chain of reporting on PP issues, and how will the final determination be made? How likely are these dark streaks special regions? Are they just erosional features or are they liquid? NASA will also convene a workshop with planetary scientists and terrestrial geologists to document points in the decision-making process. Dr. Grunsfeld has also ordered an assessment of the current contamination potential of the MSL rover. Is it clean enough to approach one of these regions; e.g., to use the stand-off laser to study such a region?

Dr. Lindberg commented that as the Mars Exploration Program (MEP) is considering a restricted Earth-return mission with regard to eventual sample return from Mars, he was pleased to hear about protocols for Mars surface operations that actively incorporate PP concerns. Dr. Grunsfeld felt that one practical approach would be to flag areas of concern and to think of the surface in terms of exploration in Antarctica, where the protocol is to identify and report areas of concern if they are contaminated. It is believed that Curiosity's wheels have been scoured to the point that they no longer carry spores; Dr. Grunsfeld has requested a statistical analysis of this probability, which is not yet complete. Dr. John Rummel commented that the warm electronics box on the rover is a bigger issue than the wheels, and welcomed the development of a Mars surface operations protocol as a great response to PPS recommendations. The REMS instrument can examine brines at Gale Crater and provide some data for an operations protocol. Dr. Penny Boston added that there is little grasp of the transport process under conditions on Mars, the effects of static electricity, and the means of propagation of contamination. Budgets have not reflected the urgency of these gaps in information, and the feeling in PP is that it is continually lagging. Science must be in a more informed position to tackle these new questions. Dr. Grunsfeld agreed, and felt that NASA is still suffering from the Viking "Mars is dead" viewpoint. Fortunately, the field of astrobiology is expanding into the mainstream, and SMD is investing more in trying to understand how missions might recognize life elsewhere. Because of REMS, the MSL mission does in fact have a better transport model, as well as more knowledge of diurnal flows that can start to be mapped to local topography.

Dr. Peter Doran noted that the MSL mission was explicitly designed not to detect life, and asked whether it was truly equipped to advance knowledge of the RSLs. Dr. Grunsfeld replied that this question is the motivation for the aforementioned workshop, whereby he was hoping NASA could at least advance the knowledge of these features. It's important that the Agency is moving in the right direction by putting these considerations in Mars operations. The radiation environment and local chemical environment are very harsh: can we tell from what's left over that life had actually been there? What bits of organic molecules are indicators of past life? Dr. Grunsfeld assured PPS that as SMD AA, he is the responsible party for assuring compliance with the documented requirements. What is yet to be determined are the confidence levels on the probability of contamination, and how results are reported to the Agency, the US government, and other requisite parties. This may be a topic of consideration for the National Academies of Science (NAS). Dr. Rummel commented that NASA does not currently incentivize people to develop instruments that can be sterilized by dry heat microbial reduction (DHRM), representing a hurdle to developing spacecraft/rovers that can actually contact special regions. That is an area of inquiry that can be subjected to investment, to fix that shortcoming. Dr. T.C. Onstott mentioned a Martin-Torres paper that has suggested that conditions at Mars might permit the condensation of perchlorate brines at roughly 15-20 cm below the rover wheels, and wondered if the rover could sample this layer, given that the environment is very unlikely to support life. Dr. Grunsfeld responded that those are questions that will be addressed at the upcoming workshop. He noted that RimFax, an instrument in the Mars 2020 payload, would provide an exciting opportunity to explore the subsurface.

<u>Planetary Protection Issues and Updates</u>

Dr. Catharine Conley, Planetary Protection Officer (PPO), gave a briefing, invoking the NASA 2014 Strategic Goal that informs the PP policy. PP issues were recognized before Sputnik and are codified in NASA policy and procedural documents NPD 8020.7G and NPR 8020.12D, as well as a recently released policy instruction, NPI 8020.7 The NASA Policy on Planetary Protection Requirements for Human Extraterrestrial Missions is informed by science and by a range of advisory groups. The PPS considers interpretation of NASA policy documents, reports from individual missions, and the development of PP technologies. The PPS has recently recommended including PPO early in mission planning and design, a recommendation that has been successfully adopted in practice. In November 2014, PPS recommended improved communication between the PPO and the MSL Project Office. Dr. Conley observed that that PP communications had greatly improved with missions in development, such as the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSIGHT). In June 2015, PPS recommended that Mars 2020 receive a Category V Restricted Earth Return designation.

Recent PPO activities include: the initiation of a response to the MSL lessons learned study; continued cross-directorate coordination; carrying out internal activities with respect to supporting and developing an Office of Planetary Protection Operating Plan; separation of implementation activities in the Planetary Science Division (PSD) from the regulatory and oversight roles of PPO; and close work with missions that are both active and in development. PPO looks at all planetary missions and, as an example, held a recent interim review of Cassini-Huygens to confirm spacecraft reliability. The review found no degradation in the mission, with the exception of some reaction wheel degradation that will not affect orbital maneuvers. Cassini will undergo one more set of PP reviews before its anticipated impact on Saturn. In the New Frontiers program, the New Horizons, Juno and Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer

(OSIRIS-REx) missions have all been deemed to be in compliance with PP requirements. In the Discovery program, two Venus, several asteroid missions, and a proposed near-Earth camera are not high on the PP list of concerns.

InSIGHT is going to a "flat, dry, boring place" on Mars to measure seismic activity and to place a heat probe below the surface. Dr. Conley noted the mission has thus far been very proactive in implementing planetary protection requirements. InSIGHT will carry a secondary payload of two CubeSats designed to provide additional data return as the spacecraft lands on Mars. The PPO is currently working out the compliance issues for the proposed CubeSats as an ongoing activity.

Planetary protection concerns have arisen in the wake of Curiosity results. There have been detections of methane and observations of higher humidity than initially anticipated within the landing ellipse that had been the area of review for PP. Outside the ellipse, the mission is now seeing evidence of RSLs that has initiated PP analysis of the traverse path, which contains many dark streaks; these dark areas are of potential concern for the presence of special regions. In the summer of 2015, a blogger observed that the rover had left tracks near a 0.5- to 1.0-meter scarp that appeared to harbor some of these dark streaks, raising the question as to whether any microbes had been introduced into special regions at the Bonanza King Outcrop. A reasonable way to frame the problem of "How close is too close?" is to calculate the probability of introducing 30 microbes from a particular distance.

There are several possible mechanisms for spacecraft-induced special regions that may be relevant now and in future missions to Mars: an off-nominal impact can deliver an RTG to the surface; the rover can heat the ground during nominal operations and can create what Dr. Conley described as a "teakettle problem" (inducing hydrated minerals to release water vapor into an enclosed environment). The temperature gradient on the rover resulting from heat transfer from the radioisotopic thermal generator (RTG) to unheated surfaces can also create a special region when 100% relative humidity air condenses at night. These and other considerations, as well as the expectation of new discoveries at Mars, have led to a Category V classification for the Mars 2020 rover.

Planetary protection has garnered much media attention of late, including a profile of Dr. Conley in the *New York Times*, an article in *New Yorker* magazine, and a radio interview. The Research Opportunities in Space and Earth Sciences (ROSES) program research budget for PP is increasing at a modest rate, with one PP research proposal to ROSES 2015 in review. The Planetary Protection Research (PPR) solicitation encompasses these themes: characterize the limits of life in laboratory simulations of planetary environments or Earth analogs; model planetary environmental conditions; develop or adapt molecular analytical methods to detect/classify the widest possible spectrum of Earth microbes; and identify sterilization technologies that are compatible with spacecraft materials and assemblies. Some 2014 ROSES selections included a study of dry heat inactivation of embedded spores and evaluations of microbial hardiness. In response to a question, Dr. Conley explained that a PPR call comes out annually if there is a budget, and that she also tries to fund one new graduate student per year. Awards range from one-year pilot studies to a full, four-year study. Dr. Michael Imperiale asked if any thought had been given to developing new materials for spacecraft that resist colonization by microbes. Dr. Colleen Cavanaugh noted that medical science might have much to offer in this case, as in materials used for implantation of microbe-resistant stents, etc.

Planetary Science Division Update

Dr. James Green, director of the PSD, gave a briefing on division activities. The MESSENGER spacecraft impacted Mercury in late April of this year, and is continuing to analyze data. New Horizons has completed its flyby of Pluto and Charon, and recently posted the highest resolution photos yet of the system. The Europa mission has gone through phase A of development, and will reach Key Decision Point-B (KDP-B), a significant mission milestone, in the next calendar year. Europa instrument selections have been completed. The Dawn spacecraft arrived in 2015 at the asteroid Ceres. Dawn is now moving to its lowest altitude orbit to start a final set of observations and mapping maneuvers over the next 5 months. PSD has received Step-1 proposals for the next Discovery call. JAXA's Akatsuki spacecraft finally succeeded getting into orbit at Venus, five years after initial attempt. NASA has eight Participating Scientists on the Akatsuki mission, and has contributed a group of navigators from the Jet Propulsion Laboratory (JPL), as well as support from the Deep Space Network (DSN). Upcoming events include the launch of the European Space Agency (ESA) mission, the ExoMars Trace Gas Orbiter. NASA has some investigators on the mission, and will also contribute DSN support, for using ExoMars as a relay for landed assets. Both InSIGHT and Juno will launch in 2016. In late 2016, PSD will make the downselect from five missions to one in the Discovery program. The five current selections are Psyche (to explore Asteroid Psyche, a metal world and demonstrate deep space optical communications); NeoCam (infrared observations of near-Earth objects and a deep space optical communications demonstration); Lucy, a Trojan asteroid mission with advanced solar arrays; VERITAS (a Venus mission using synthetic aperture radar); and DAVINCI (a probe into Venus's deep atmosphere). PSD is trying to return the Discovery program to a three-year cadence of announcements and selections.

In the New Frontiers program, PSD has selected nine ROSES proposals for advancing instrument TRLs. OSIRIS-Rex is on schedule for a September 2016 launch. The mission will return a sample from Bennu, a carbonaceous chondrite asteroid, in 2023. A proposal has been made for a secondary target for New Horizons: another Kuiper Belt Object (KBO) named 2014 MU69. Course corrections have been made to reach this object, the proposal for which will be subject to a Senior Review. Juno is on track to enter orbit at Jupiter in July 2016. The spacecraft will enter a polar orbit outside Jupiter's radiation belt, where it will spend a year making gravity measurements, assess the depth of the water layer (greater than 100 bars), and record latitudinal and longitudinal variations. In answer to a question, Dr. Green noted that the New Horizons data relay would be completed by the end of 2016.

Both New Frontiers #4 and #5 selections have been released, addressing the top five science objectives of the Planetary Decadal Survey, while radioisotope power system (RPS) mission planning continues. New Frontiers call #4 will have access to three multimission radioisotope thermal generators (MMRTGs). A higher efficiency version of an MMRTG is also being developed, and may be available in the same timeframe. The Europa mission would carry out 45 low-altitude flybys (lowest altitude to be 25 km) of Europa from the orbit of Jupiter, to acquire a global view of the body. The same strategy was used to map Titan. The mission would investigate the ice shell, ocean, interior composition, geology, and tidal forces of Europa, as well as acquire high-resolution imaging to provide data on future landing sites. The mission would not use radioisotope power. Data would be stored on board and radioed back to Earth when the spacecraft is at its furthest point from Jupiter. Mission development is doing well in terms of both mass and power margins.

PSD also has plans for two CubeSats, one of which is a lunar polar hydrogen mapper and the other a particle aggregation and collision experiment. Also approved for one-year studies are a Mars microorbiter, an asteroid visitor ion-drive concept, and a hydrogen albedo lunar orbiter. PSD has also initiated studies at NAS, including one to review the restructured research and analysis (R&A) program to determine whether program elements are still appropriately linked to the science. The division has also initiated a JPL affordable-mission concept study to visit the ice giants, to prepare for the next Decadal Survey. The study will consider the use of an Atlas-like evolved expendable launch vehicle (EELV) or the Space Launch System (SLS) to reach these bodies. The range of concepts is constrained to be $2B or less in FY15 dollars, and the results will be subjected to a Science Definition Team (SDT) analysis. PSD has asked ESA to participate in the SDT. Another concept, AIDA, an ESA/NASA asteroid impact hazard mitigation mission, is also being evaluated. AIDA would use a kinetic impactor to deflect an asteroid. AIDA is in pre-phase A study, and would be designed to intercept a secondary member of a binary asteroid system, launching in October 2022.

Discussion

Dr. Lindberg, referencing October's Cassini spacecraft maneuvers through the plumes of Enceladus, asked how the mission went through the process of assuring against contamination. Dr. Green, noting the maneuver passed within 15 km of the surface, reported that there are excellent results that will be presented at the American Geophysical Union (AGU) conference; the data is still under analysis. AGU will have an Enceladus session on Monday afternoon. Dr. Green promised to get back to Dr. Lindberg on the contamination issue. Dr. Boston noted 4 of 5 Discovery selections were female PIs. Dr. Meenakshi Wadhwa asked whether PSD would be able to select two Discovery missions. Dr. Green explained that he had asked all five selectees to study alternative launch windows, to allow for that possibility. In addition, he was trying to get the New Frontiers Announcement of Opportunity (AO) as soon as possible, and was developing a community announcement at present. Some of this activity depends on a passed budget, but he expected to get the AO out before the end of the fiscal year. Dr. Goeres expressed concern about the quality of data being sent back from New Horizons. Dr. Green responded that the data benefit from a high signal-to-noise ratio, and that in addition the DSN has corrective capabilities. Data are stored on board, and can always be re-transmitted. Dr. Boston asked if it would be feasible to consider radiation to serve as a means of reducing the bioburden for a Europa lander. Dr. Green replied that this consideration would be folded into a mission study.

Mars Exploration Program Update

Mr. James Watzin, MEP Director, provided a status of the program. Numerous operational assets are in reasonable health across the board. Two orbiters are getting a bit old: the Mars Reconnaissance Orbiter (MRO) is 10 years old, while Mars Odyssey is 14. The Curiosity and Opportunity rovers are continuing to operate. Opportunity has a memory issue that is worsening, and is being held in limited operations, in winter mode. Mars 2020 is heading toward a key milestone, a Preliminary Design Review (PDR), which will be held in the first week of February 2016, and is progressing very well through subsystem PDRs. The Mars Organic Molecule Analyzer (MOMA-MS), a mass spectrometer destined for the 2018 ESA ExoMars mission, has been delayed somewhat due to delivery issues with the German contributor. Long-term, MEP is dealing with an aging infrastructure, and will need assets in place for future missions. Also, in response to the Decadal Survey, the program must consider missions beyond 2020 to complete sample return. He noted that the 2022 opportunity is five years from the current budget-planning horizon, so it is time to start thinking about the future. The program hopes to get to pre-phase A for the next mission in short order, given the need for future orbital reconnaissance. Mr. Watzin believes that at least the baseline elements will be healthy for the Mars 2020 mission.

A joint MEP/Human Exploration and Operations Mission Directorate (HEOMD) Human Landing Site Workshop has been conducted. Mars 2020 conducted a second landing site workshop in August, in the context of ongoing imaging and analysis of top landing sites. The mission also completed a heritage flight system review in September 2015. Early acquisition and builds of heritage elements are proceeding at a fast pace. The mission also completed the Sampling and Caching System (SCS) architecture definition, has held a large number of subsystem reviews for payloads, and is generally on track. Dr. Rummel asked about a possible "helicopter" concept as being included in Mars 2020. Mr. Watzin reported that the concept was under study by the Science and Technology Mission Directorate (STMD), potentially for reconnaissance. However there has been no decision to build or fly such a craft, but resources are being held for it if it turns out to be feasible.

NASA continues to plan to contribute the mass spectrometer (MOMA-MS) for the ESA 2018 ExoMars mission and is pressing ahead, having completed development while overseas partners pursue theirs. The NASA portion of the flight unit has been built and instrument performance has been tested. The German contributor has been delayed in getting the flight laser assembled, such that integration into the entire mission will be delayed. The NASA contingent has had to slow down team efforts, and may have to truncate instrument capability to accommodate the new schedule.

In the Journey to Mars, it is expected that robotic assets will fill gaps in knowledge, and that MEP must work through the engineering aspects of future exploration needs. Over the last 6-9 months, STMD, HEOMD, and PSD have held joint dialogues in areas such as the orbital environment and operations; capture; entry, descent and landing (EDL); ascent from Mars; and surface operations at Mars. More information is required about resources at the planet that can support surface operations and about the round-trip experience. MEP plans to build on robotic experiences to understand the needs for the larger human operational experience. The program has placed exploration technology instrumentation on the Mars 2020 backshell, to inform the design of future entry shells, and will include an in-situ resource utilization (ISRU) experiment to extract oxygen from the Martian atmosphere, as well as other in-situ and sample science. A new orbiter in the 2022 timeframe is now recognized as a next step to replenish assets in place. A 2022 orbiter could add or improve remote sensing for human exploration needs. Following placement of an orbiter, the next step would be to evolve EDL design and architecture for round trips, a Mars Ascent Vehicle (MAV) design, and the capabilities of ISRU. Dr. Lindberg commented that the planning seemed to imply a shift from science-focused missions to human exploration. Mr. Watzin replied that ongoing science objectives and missions will continue, while MEP will also want to also answer human exploration questions as the missions move forward.

Joint activities between MEP and HEOMD include a Human Science Operations Special Analysis Group, which is addressing new science enabled by human presence on Mars. A Human Landing Site Study (HLS^2); ISRU and Civil Engineering (ICE) Working Group; and Next Orbiter Science Analysis Group (NEX-SAG) have also been established. The NEX-SAG will issue a final report shortly; its findings include: a recognition of solar-electric propulsion (SEP) as an advantageous technique; the need for advanced telecommunications to provide necessary coverage for high-resolution data; and an overlap between science and human exploration resources that yields similar interests for more mature instrument approaches. NEX-SAG considered orbiter capabilities such as visible imaging; polarimetric synthetic aperture radar (SAR); shortwave IR spectral mapping; thermal IR sounding; and multiband thermal mapping.

The HLS^2 study considered 43 potential sites, some of which harbor water-ice, sulfated minerals, and hydrated rocks. Next efforts will be to group these sites into categories and obtain reconnaissance data to inform the next workshop. HLS^2 had about 150 participants. Almost all presenters addressed the question of life, as well as potential in-situ resources. Study results will be posted soon.

In summary, MEP is healthy and meeting its milestones. Collaboration with HEOMD is working well, and operational assets at Mars are aging but still supporting mission needs. Planning for the future is a pressing priority. Dr. Doran commented that at some point there will be a convergence of rover and human endeavors and asked if it were still necessary to carry out sample return before sending humans to Mars. Mr. Watzin felt the question was still up for debate, but that the conversation is advancing. Dr. Boston asked how fast the next orbiter could be formulated, given a catastrophic failure of present assets. Mr. Watzin cited a 5- to 8-year planning horizon, maybe a year less. MEP is studying whether this can be pulled off for 2022. Dr. Steneck asked about civilian efforts to put humans on Mars. Mr. Watzin was convinced that it is technically possible, but it would require a national will and persistence, and a long-term commitment. However, he felt it was very unlikely that a commercial effort could succeed, thus lowering any attendant risk of contamination at Mars any time soon. He also felt it would be realistic to send a rover and a MAV before 2026, putting earliest sample return at about 2030. NASA would have to start thinking about a sample-return facility (SRF) in about 2020. Dr. Imperiale asked about the status of the discussion of potential human contamination of Mars. Mr. Watzin felt that NASA needs to start having the discussion of what that means, and that it would involve agencies well beyond NASA. Dr. Goeres asked how contamination was avoided during the integration of multiple instruments from multiple contributors. Mr. Watzin replied that decontamination standards are maintained during the subsystem build up, while clean conditions were maintained at the integration facility and during transport.

Discussion

Dr. Lindberg observed that the Grunsfeld directive to establish a detailed PP protocol during Mars surface operations is welcome news. Dr. Wadhwa commented that greater investments in technology that will enable rovers to visit potential special regions is worthwhile, and that PPS should talk about it in the broader context of technology development at NASA. Investments in new materials, and other technologies for building clean rovers with full systems for querying the surface should be discussed. Dr. Lindberg raised the emerging question of "How close to approach?" How close can we get to special regions to analyze and understand them? NASA needs to stay ahead of the question. Dr. Rummel noted that that's where the understanding of transport processes comes in. Mr. Watzin commented that the RSLs have only been confirmed on steep hillsides, which are currently not accessible to Curiosity. Dr. Cavanaugh asked how one might consider using a microbe-resistant coating for a spacecraft. Dr. Lindberg felt it could encompassed within a ROSES call, with the right collaboration. Dr. Conley noted that there is a PPR element that could encompass such a study, which could eventually be turned over to a mission, which could then put more money into investment and development. Dr. Lindberg suggested an STMD workshop as a vehicle for bringing in materials experts from the medical community. Dr. Goeres commented that PPR could be a first place to evaluate whether such materials would be promising.

Dr. Lindberg noted that Gale Crater had been the least likely of sites in terms of fear of contamination, and previous missions had not had to deal with it in terms of their science objectives. Dr. Green said that from orbit, it seemed clear that the stratigraphy on the central peak had to be due to deposits, which did hold a suggestion of past habitability. He felt that a potential assessment of Curiosity's bioburden should be quite possible under these circumstances. Asked about the status of methane measurements, Dr. Green reported that the mission is still analyzing the data, and must take the appropriate care to consider all interpretations. MEP is continuing to take the measurements, using enrichment techniques and probing at the appropriate times to determine whether other methane spikes are present.

<u>COSPAR Panel Colloquium: Report on Mars Special Regions</u>

Dr. Vicky Hipkin, Vice Chair of the Committee on Space Research (COSPAR) Planetary Protection Panel, reported out on a COSPAR colloquium that was held by invitation in Bern, Switzerland, in September 2015. The meeting included representation by Drs. Lindberg, Conley, Rummel, Boston, and Doran, members of the European Space Foundation (ESF)/National Research Council (NRC) Joint Study on Mars Special Regions, and the Japanese Aerospace Exploration Agency (JAXA). The first topic under consideration was Mars Special Regions, a concept established in COSPAR policy during the last decade, initiated by a MEPAG study in 2013/14 and followed by the ESF/NRC study. The final report of the colloquium is due in April 2016.

Special regions are defined by two parameters: temperature and water activity, which allow microbial growth to occur. A minimum temperature of -25°C was established, based on data in the 2006 exercise and 2007 update to policy. A new temperature assessment, arising from the proceedings of the colloquium, requires that the temperature parameter to be extended to -28°C, which includes a margin of 10°C. More experiments may indicate support for a relaxation of such margins in the future. The Colloquium also concluded that a special region assessment must include an assessment of the extent to which the temperature and water activity parameters specified are separated in time. With respect to gullies and caves at Mars, the Colloquium recommends that gullies of taxon 2 through 4 (as defined by the MEPAG-SR-SAG2 report) must be treated as special regions until proven otherwise. Further, the Colloquium recommends that caves and subsurface cavities must be treated as special regions until proven otherwise. Dr. Boston observed that present data indicate that there are roughly 2000 pits/lava tubes on Mars.

The Colloquium recommends that confirmed and partially confirmed RSLs must be treated as special regions until proven otherwise, that candidate RSLs must be evaluated on a case-by-case basis, and that specific definitions of observational evidence for RSL be confirmed- observed incremental growth of flows.

The Colloquium recommends that sources of methane be added to the list of sites that must be treated as special regions until proven otherwise, and also that maps should be dated and only used to illustrate the general concept of special regions, but these same maps cannot be used to delineate the exact locations of special regions. Furthermore, planned 3-sigma pre-launch landing ellipses must be evaluated on a case-by-case basis as to whether the mission would land or come within contamination range of a special region, based in part on the morphological characteristics of the ellipse. The Colloquium recommends a modified and stronger wording of the guiding principles on the determination of special regions, and also recommends certain deletions and replacements of language in the implementation guidelines.

Future research recommendations include studies on the propagation of microbial life in the absence of liquid water, time-delayed storage and utilization of water or energy for growth and reproduction, water activity in pore spaces, methane production and localization, and translocation of viable biological contamination on Mars. Dr. Lindberg added that in discussions about the treatment of methane sources, atmospheric methane was not considered a source (i.e. non-localized methane). Dr. Hipkin noted that comments from members of the ESF/NRC Joint Committee would be addressed before publishing the colloquium report.

COSPAR Panel Colloquium: Position Paper on Icy Worlds Planetary Protection
Dr. Rummel provided a briefing on a position paper resulting from the Icy Worlds discussion at the COSPAR Bern Colloquium, which arose from interest in the international science community, and ongoing studies. Both Enceladus and Europa exhibit plumes, which suggests that there is some communication between the interior and exterior of their icy shell. This paper provided input to the second consideration of the Bern Colloquium, planetary protection considerations for icy worlds.

The 2009 COSPAR workshop on Planetary Protection for Outer Planetary Satellites and Small Bodies recommended adding Enceladus to PP Categories III and IV. This recommendation was adopted by COSPAR and introduced into the COSPAR Planetary Protection Policy. The Colloquium, considering results from the paper, recommends extending Category III/IV Planetary Protection requirements, established for Europa, to Enceladus. The Colloquium also added a sentence on holding the probability of inadvertent contamination at 1×10^4, and further recommends that papers on the topic of biological contamination requirements, for Europa and Enceladus in-situ life detection and sample return missions, be presented to the biennial 2016 COSPAR conference to be held in Istanbul, Turkey.

The Colloquium recommends modifying language in the Category V policy statement, and modifying language on sample return missions from Europa/Enceladus. It was generally recognized that contamination analysis would benefit from further work, including determining the response of organism to high-velocity impacts and high-radiation environments.

Dr. Cavanaugh asked if exoplanets had been considered in planetary protection discussions. Dr. Rummel commented that they are probably safe thanks to humankind's low probability of visiting one. Dr. Conley noted that an assessment had actually been done for Voyager, and the calculation had concluded that it would be 40,000 years before Voyager might reach an exoplanet. Dr. Green added that NASA would be participating in ESA's 2022 Jupiter Icy Moons Explorer (JUICE) mission: a Ganymede, Callisto and Europa explorer.

Meeting with European Space Agency's Planetary Protection Working Group
Dr. Lindberg reported on the results of a joint PPS/Planetary Protection Working Group (PPWG) meeting, explaining that PPWG is ESA's rough equivalent of PPS. The first joint meeting between the groups was hosted at Kennedy Space Center in 2011. At that time, participants discussed Mars landing site selection processes, joint engineering studies on Mars sample return, and PP technology investments, and agreed on the value of continuing joint meetings, while setting a goal of conducting them once every two years. PPWG issued an invitation to PPS to attend its October 2015 meeting, and PPS managed to send a limited representation comprised of Drs. Lindberg, Rummel, Imperiale, Wadhwa, and Onstott, all attending as fact-finders. Dr. Conley attended as a member of the PPWG. Dr. Kaminski also attended, as did the State Department's representative, Dr. Teplitz. The 2015 meeting including a briefing on the REMS instrument on the Curiosity rover and the HABIT instrument on ExoMars. REMS is a weather station on Curiosity, while HABIT is an instrument for ExoMars that will study the process of brine formation, and investigate the habitability of the

landing site and the exchange of water between the atmosphere and regolith. HABIT has been selected for flight on ExoMars.

The PPWG and PPS heard a briefing on a proposed United Arab Emirates (UAE) Mars orbiter mission as well as reports on the aforementioned COSPAR Colloquium on Mars Special Regions and Icy Bodies, the ExoMars landing site selection process, European Cooperation for Space Standardization (ECSS), ESA R&D for Sample Return, NASA/ESA Biodiversity Assessments, and ongoing and planned missions for both agencies.

The UAE Mars orbiter mission is in its planning stages. The Mars orbiter is focused on atmospheric weather and climate processes. The Principal Investigator (PI) is a member of the royal family. He understands and is committed to complying with international PP standards. Dr. Gerhard Kminek, the Chair of the COSPAR PP Panel, has offered ESA technical support to the project.

ECSS, established in the 1990s, represents the process whereby Europe manages PP standardization among multiple nations across multiple missions. ECSS is an agreement between ESA, European National space agencies, and the European space industry. PP-related ECSS standards include bioburden control of cleanrooms, material compatibility with sterilization, dry heat sterilization standards, vapor phase bioburden reduction (hydrogen peroxide), and microbial examination (assays).

PPWG made several recommendations that will go forward to the ESA PP Office. These recommendations include: a move to next-generation sequencing to catalog biodiversity assessments (to provide an inventory on organisms) on flight hardware; embrace the recommendations from the September 2015 Colloquium on Mars Special Regions and Icy Moons, and recommend their use on an interim basis until adopted by COSPAR. The gathering also heard mission updates on ESA's JUICE, ExoMars 2016 and 2018 missions, and NASA's MESSENGER, Dawn, New Horizons, OSIRIS-REx, and Europa "clipper" missions.

Discussion

Asked if a launch vehicle selection had been made for Europa, Dr. Green said that PSD is discussing the use of additional mass for some sort of element (from ESA, perhaps) next year, at phase B. Mission planning is still maintaining conformance with an EELV and SLS, but that decision won't be made until PDR. Similarly, the Asteroid Redirect Mission (ARM) has not made an launch vehicle decision yet. Dr. Goeres asked if there had been any discussion at the PPWG on optimizing methods for assays. Dr. Conley explained that optimization was based on the principles of affordability and utility, and is analogous to water quality assessments. Materials must also be compatible with the assays and vice versa. Dr. Imperiale suggested thinking about future material design that accommodates needs of PP. Dr. Conley agreed and said it was a particular challenge for MEP. For the human exploration side, NASA can incorporate some longer-lead future options in technology development. NASA has recognized it can do better than the Viking era. Dr. Lindberg suggested having a briefing on the proposed HABIT instrument, which would be inducing a special region and would require commensurate sterilization measures.

<u>MSL Gale Crater Observations</u>
MSL Project Scientist Dr. Ashwin Vasavada reported on the latest observations from the Gale Crater, which may be relevant to planetary protection. Two questions to consider: Has Curiosity measured unexpected conditions? Have features formed by liquid water been found in Gale Crater?

Measurements and observations at Gale Crater, from the Mars Global Survey Thermal Emission Spectrometer, indicated a column abundance of water vapor from 5-20 microns in thickness. Measurements from Curiosity's REMS instrument, indicate that temperatures range from -75°C to near 0°C at around noon. Relative humidity is basically zero for much of the Martian day, but it can rise to close to 50% at night, measured at 1.6m above the surface. Relative humidity during the cooler times of day can rise to values of as much as 60-70%. Models suggest that these conditions allow 10 or so precipitable microns of water vapor. These data are very similar to what was predicted prior to landing, as to the overall abundance of water in the atmosphere. Gale Crater is extremely cold and dry as predicted, and similar to Mars in general. Water vapor is present in the tens of parts per million in the atmosphere. Even with that small amount of water vapor, however, there could be exchange with the regolith on a daily basis through adsorption, or exchange with hydrated minerals or salts. These processes don't involve the liquid phase (with the exception of deliquescence). Relative humidity is near zero for most of each sol, but there is still the possibility of frost or brine formation at ground level, at the coldest temperatures at night.

A paper by Martin-Torres in *Nature Geosciences* (13 April 2015) on transient liquid water, contains a key figure showing a phase diagram for calcium perchlorate salt, indicating that conditions throughout the Martian year are far outside those defined by COSPAR as special regions. There are a few instances, however, where conditions are close to allowing liquid formation. REMS measurements have been within equilibrium conditions for calcium-perchlorate brine for several hours on nights in the winter season. In summary, equilibrium conditions for perchlorate brines are predicted during the night for some sols of the mission, primarily in winter. Equilibrium conditions do not necessarily result in brine formation, however, and there is no direct evidence of brines or frosts at Gale Crater. The key implications of the Martin-Torres paper are that equilibrium conditions for brine in Gale Crater are far from those considered necessary for special regions. However, given that perchlorate salts are widespread across Mars, brine formation may be more likely than previously thought. The difference between ground temperature and temperatures at 1.6 m above the surface can be 5-10°C at night, which could push relative humidity up to 100%. The Dynamic Albedo of Neutrons (DAN) instrument measurements suggest that there is a dry layer near the surface, and below that there is water-equivalent layer of 5-10% water. The assumption is that this layer is composed of hydrated minerals; the paper also considers that these may also represent permanently hydrated perchlorates, equivalent to a buried permafrost.

As to dark slope features, the science team did not take much note of these initially, as these are expected geologic features. A feature noted at Hidden Valley on sol 707, during the Mars southern spring equinox, about 8 inches in length, suggests some flow. High-resolution images over several sols showed a suggestion of sand flowing through cracks in rocks, and geologists interpreted the features as dry avalanches of sand, bolstered by visible evidence of dark, loose sand that is revealed after surface sand, which is brighter orange dust, is moved by rover wheels, or by avalanche. It is possible that the avalanches are triggered seasonally by vapor adsorption, frost, thermal contraction, etc. There are other images of slumping sand from sol 969 in summer, and sol 1146 in fall. In summary, these small dark slope features have been interpreted as mini-avalanches. Ongoing systematic measurements will catch hydration at the surface, if present, and no such discoveries have been made to date. ChemCam and DAN have not captured evidence of hydration, despite looking for it every day throughout all seasons. DAN can get to 0.1% sensitivity level for detection of hydrogen, within a wide field of view, while ChemCam has a narrow field of view, with detection to about the 1% level.

Candidate RSLs on Mt. Sharp have been observed at Gale Crater latitudes, wherein salts have been detected; this was announced in September 2015. At sites 12 and 13, two candidate RSLs (about a meter in width and in the low tens of meters in length), are close to the traverse path of the rover over the next few years. MSL has updated the PPO on all information from the MRO HiRISE instrument. The planned route up Mt. Sharp will keep the rover more than 2.5 km from these candidate RSLs. The rover will have a better capability of resolving these features (compared to HIRISE orbital assets) as it reaches its closest approach. It is expected that the areas will be too small for the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument to resolve.

At present, the MSL team is developing a new operations protocol for planetary protection, and is getting a better understanding for the potential for special regions, to assure that the mission does not introduce hardware into prohibited areas. The protocol is to be used every day, and is still working its way up to the PPO. The current question remains whether these small local slope features should be approached and studied. ChemCam could be used first (from 3 meters away) to query the bright and dark features to determine their hydration states, and the full laboratory could also be used, scooping the material and analyzing it. Dr. Onstott was curious whether the team had made an effort to locate the source of methane or to coordinate the tunable laser spectrometer (TLS) with REMS or DAN measurements. Dr. Vasavada said that the current period is within the window of last year's spike, and while the science team has increased the rate of measurements, another methane spike has not been detected.

<u>Mars 2020 Planetary Protection Requirements</u>

Dr. Conley presented an update on Mars 2020 PP requirements for sample collection and return to Earth. All Mars Sample Return (MSR) requirements are consistent with Space Studies Board recommendations arising from multiple reports on PP considerations for MSR. It is important to understand what measurements signify: these can be true positives, false positives, false negatives, or true negatives. False negatives are the highest priority concern for Mars policy. According to

Presidential Directive NSC-25, which governs the conduct of the experiment, MSR preparations must consider any outcomes that have major potential for adverse effects. All flight elements of an MSR effort that have been exposed to the Martian environment to be returned to Earth are considered as Category V/restricted Earth return. Campaign level constraints include the requirement that all items returned from Mars are to be considered hazardous until demonstrated otherwise. The presence of an RTG would impose landing site restrictions to prevent spacecraft-induced special regions, while assuming instrumentation is at least as sensitive as today. Additional work will be necessary to assess current capabilities and to extrapolate future needs. A partial categorization letter was sent to the Mars 2020 team in May 2015; additionally a December 2015 letter, based on known data, has been sent to supplement the original letter. While overall Mars 2020 is regarded as a Category V/restricted Earth return, the outbound leg of Mars 2020 is categorized as Category IVB as implemented at the subsystem level. All changes to level 1 requirements relevant to Planetary Protection shall be submitted to the PPO for approval. Mars 2020 shall prevent contamination by Earth compounds of Mars materials subjected to in-situ analysis above the levels negotiated with instrument providers.

As to landing sites, Mars 2020 must avoid special regions; these are classified as gullies and bright streaks associated with gullies, pasted-on terrains, subsurface below 5 meters, dark streaks, possible geothermal sites, and fresh craters with hydrothermal activity. For consideration of spacecraft-induced special regions, this concept needs work, such as more data on relative humidity conditions.

Caching requirements for hardware subsystems require that pre-launch hardware cleanliness to be verified by test, to be cleaned to a level of 300 heat resistant spores per square meter, and to include a microbial inventory of at least 99% of nucleic acid sequences. Requests for deviations from category IV have also been defined; deviations must be supported by evidence that the deviation will achieve results equivalent to those required by NPD 8020.7. Recontamination prevention also needs work, as the possible mechanisms for contamination transport must be further elucidated. For restricted Earth return elements, a large amount of documentation will be required to demonstrate to future decision makers as to whether or not samples can be returned. Sample tubes shall be designed for opening after return to Earth in a manner that prevents additional contamination.

Mars 2020 must also provide information about returned samples that will eventually be included in documentation for a future Earth safety analysis, including an Earth pre-entry report and an end of mission report. A sample containment approach, as well as a decontamination approach (if needed), must also be enumerated and documented. Open issues remain with determining the statistical confidence that must be met to permit samples to be returned: How confident are we that life can be detected, if contained within the sample? What material will go to destructive testing for planetary protection? What criteria will allow release of unsterilized samples from containment?

Discussion
Dr. Adam Steltzner questioned the relevance of the symmetry of effective containment. Dr. Conley noted that one was more likely to get a false positive or negative: either the presence of Earth life in the sample, or too much Earth life blotting out Mars life. Dr. Steltzner felt that the negatives would never be proven. Dr. Cavanaugh quoted the adage “absence of evidence is not evidence of absence.” Dr. Wadhwa felt that the stated restrictions would imply that the only samples ever to be released would have to be sterilized first. Dr. Lindberg agreed that such a scenario has been widely discussed, and added that part of the challenge would be to adequately address the interests of the international community. Dr. Onstott asked to what extent had ethylene or chlorine dioxide been considered as a sterilization method. Dr. Conley deferred to the flight hardware developers on this issue. Dr. Onstott asked to re-address the question at some point.

Public comment period
No comments were noted.

December 9, 2015

Welcome
Dr. Lindberg opened the meeting. Dr. Kaminski made brief remarks; members and attendees introduced themselves.

Words from the Chair
Dr. Lindberg reported having provided the Mars 2020 team with a list of questions for a briefing that would constitute the principal subject of the day. He raised some possible observations, findings and recommendations, the first finding being to welcome Dr. Grunsfeld’s attention to the new emphasis on planetary protection during daily surface operations on Mars. Possible recommendations were: that NASA adopt the COSPAR Planetary Protection colloquium findings ahead of the full COSPAR meeting in 2016; formulate suggestions on how to approach potential special regions by Curiosity; urge greater investment in technology and exploration of new spacecraft materials that are more amenable to cleaning; develop strategies for building clean rovers, including adopting coatings that have been developed for biomedical devices to make rovers microbe-resistant. Dr. Rummel suggested recommending ways to incentivize instrument developers to make more sterilizable instruments.

Returned Sample Science Board
Dr. Hap McSween presented a briefing on the role of the Returned Sample Science Board (RSSB), which was chartered in September 2015, and crafted by the Mars 2020 scientists. The rationale for the board was to address one of the objectives of the mission, which is to prepare a carefully selected and documented set of samples for possible return to the Earth. Subsequently, the project chartered a multidisciplinary team of scientists to provide guidance for the planned execution of the mission. The board has two chairs, Dr. McSween and Dr. Dave Beaty, as well as 10 at-large members, an *ex officio* member acting as a liaison with JPL, and three observers (MEP, PP, MSR

System Engineer). The board's responsibilities are primarily to help with analyses requested by the project, and science planning documents. Observers will be copied on key correspondence or reports of the board and invited to listen to RSSB discussions, and to give technical input if requested. The board also operates with a sunset clause that states that new RSSB positions will be competed about one year before the launch of Mars 2020. Scientists on the original board may compete for a Participating Scientist role, but they will not be guaranteed selection. Dr. Cavanaugh felt that the absence of a microbiologist on the board was of concern.

Recent board tasks include the completion of a study of the effect of temperature on returned sample science. Current tasks are under way for inorganic contamination, magnetic studies, and landing site selection. Future tasks will be to develop procedural blanks for organic analyses and a dossier for cached samples. In the case of determining the effect of temperature on sample science, the RSSB was given two questions: is the expected maximum sample temperature acceptable, and is there a science case for increasing the temperature if requested? Samples will experience their highest temperature ranges while sitting on the Mars surface (70°C) and during drilling. Temperature estimates were provided by JPL thermal engineers associated with advanced planning (e.g., Pradeep Bhandari), and the Mars 2020 project team. Sample temperatures during duty cycling (drilling and acquisition) are lower than acquisition without cycling. Predicted temperatures on the surface are site-specific, with Holden and Eberswalde being the two hottest regions. The RSSB took 60°C as the maximum baseline temperature and considered 11 investigations, such as the possible effect of temperature on putative Martian organisms (unknown temperature range); however, there are no requirements on the mission to return any potential life alive. This decision has already had a direct impact on engineering; Mars 2020 engineers developed tubes with an aluminum oxide coating that will keep the maximum temperature as 60°C in any part of the sample tube (as opposed to the average tube). Other findings of the temperature study are that 60°C is acceptable for most engineering and investigation parameters. In cases of low temperature sites, headspace gas in the sample tube can be kept low. Temperature constraints for each kind of investigation are documented. Heating during drilling was based on basalt samples; softer materials would result in lower temperatures being generated during drilling. Dr. Vic Teplitz suggested the board consider the effects of solar wind, and the background of cosmic rays. Dr. McSween made note of these suggestions and said he would pass them on to Ken Farley.

The initial conclusion from studies regarding inorganic contamination is that tungsten carbide drill bits would have a significant effect on a key returned sample science (RSS) investigation (tungsten hafnium geochronology). More attention is needed to this issue. A possible workaround is to have two types of bits (the other would be diamond). Dr. Rummel asked if there were a list of key RSS investigations that is accepted by MEP and Mars 2020. Dr. McSween reported that this has not yet been done, while it was a good point to raise; meanwhile the board has been working with every investigation it can think of. He expected that investigations that can't be contemplated will eventually be done. Dr. Rummel commented that in the short term, the mission must respond to actual requirements for specific investigations.

There are currently 8 candidate landing sites: Columbia Hills (Gusev), Eberswalde, Holden, Jezero, Mawrth, NE Syrtis, Nili Fossae, and SW Melas. Magnetic studies are also in work: Mars does not have a magnetic field today, however it has paleomagnetic signatures that have been measured from low orbit. Should Mars 2020 go to one of these paleomagnetic anomalies, and select samples in such a way that magnetism could be preserved for study back on Earth?

Discussion
Dr. Lindberg asked if the RSSB would consider any planetary protection tasks. Dr. McSween felt that this was not part of the charge, but that there may be some intersection. In January, the board will consider procedural blanks, to the extent of how to characterize organic material that may be present in a cached sample. The RSSB charge is to make sure organic material is returned in an intact way. Any PP issues should be handled by a PP-specific board, and the RSSB does not have the expertise to handle such tasks. Dr. Rummel noted that somebody needs to speak for sample-caching and sample collection instruments, otherwise all the trades that come along are going to be difficult to implement. He felt that Dr. McSween should press for more expertise on the board in regard to sampling techniques and where to drop the samples. Dr. McSween agreed that as the board gets reconstituted, the expertise should stay in place. Dr. Cavanaugh reiterated her concern that there is no expert on microbial ecology on the board. Dr. McSween suggested that the omission is based on the fact that there is no stated requirement that the mission bring back live organisms. Dr. Imperiale asked what sort of assay would determine signs of past life. Dr. McSween said it would have to be a combination of observations that would point to past life, such as a stable isotopic signature, a geochemical signature that reflects redox processes, evidence of a system out of equilibrium, and morphological features. Dr. Beaty added that the Mars 2020 report identified six categories of biosignatures that subsequently informed the development of in-situ instruments. All six categories can be produced by nonbiological processes, which is why a combination of the categories is necessary to make the determination of presence of past life. Dr. Onstott commented that the potential exists for biological contamination of cores that will degrade over time, such that it will be difficult to distinguish terrestrial from Martian contamination. Dr. McSween said the board is addressing this through the procedural blank task, which will be focused on organic contamination. The RSSB does not have the expertise on the board to evaluate organismal contamination, but it does have the authority to reach out for microbiological expertise. Dr. Beaty added that the RSSB serves at the behest of the Project Scientist, and encouraged the PPS to ask Drs. Farley and Steltzner questions about microbial contamination. PPS requested a copy of the report on sample temperatures. Dr. Doran noted at the conclusion of the briefing that there is indeed PP representation on the board, which had been requested in the original solicitation.

Mars 2020 Planetary Protection - Jet Propulsion Laboratory Briefing
Dr. Lindberg introduced the briefing, whose purpose was to describe the design and operation of the Sample Caching System (SCS), the assumptions made as to PP requirements, the requirements flowdown to the SCS and its components, the level of cleanliness of SCS elements throughout the preparation to launch and operations, the means of contamination avoidance, and the level of maturity of the SCS design with respect to the PP approach.

Mr. Matt Wallace, Deputy Project Manager, introduced the briefing, describing it as a complicated set of issues that would be difficult to get through satisfactorily.

Dr. Steltzner, Chief Engineer for the Mars 2020 mission, gave some introductory background and commentary on the briefing, noting that the central challenge for the Mars 2020 mission was its unprecedented cleanliness. To that end, a subsystem sterilization approach is being used to ensure the cleanliness of the SCS; some elements will be cleaned to a Category IVa level, and some elements will be cleaned to a Viking-level standard. This requires having to seal clean elements to avoid recontamination and acquiring an understanding of operational transport features for use on Mars. Principles of cleanliness guide the architecture of Mars 2020 and represent a new approach. Mars 2020 is essentially a re-flight of the MSL, which has set some constraints through the use of heritage hardware. A bounding meta-analysis has shown good margins (>10) of cleanliness thus far. The entire spacecraft contains semiconductors and other hardware that is incompatible with dry heat microbial reduction (DHMR), as well as MMRTGs that also can't accept the conditions of DHMR. Dr. Rummel noted that MMRTGs could be developed in such a way that they will accept dry heat reduction methods. Dr. Steltzner noted that the project is just trying to understand what is being done under present conditions.

Dr. Ken Farley, Mars 2020 Project Scientist, gave an overview of the mission science and science integrity. He reviewed the conditions for obtaining biosignatures as defined by the SDT, for seeking the signs of life: the mission must look at a habitable environment, with potential for biosignature preservation, and look for potential biosignatures (not definitive evidence of past life), and seek recognition of a definitive biosignature. Such signatures can be a combination of biomarker organic molecules, minerals, macro-structures or textures, microstructures or textures, chemistry, and isotopes. There is no room on the rover for a mass spectrometer to explore the isotopic parameter, but there will be a Raman spectrometer. Mission objectives are to explore the landing site for geologic context and history; look for ancient habitable environments, identify rocks with the highest chance of preserving signs of ancient Martian life and to use tools to seek signs of this life; assemble rigorously chosen samples for future possible return to Earth; fill strategic knowledge gaps (SKGs) for future human exploration; demonstrate technology for future Mars exploration; and execute the mission within financial realities. This is an integrated set of objectives intended to support NASA's Journey to Mars. Dr. Cavanaugh commented that the in-situ astrobiology charge is skewed, as there is no life detection instrument on board. Mr. Wallace noted that the NASA program office established the science objectives, which were ultimately accepted by Dr. Grunsfeld. Dr. Farley added that there may never be a flight instrument that can definitively detect life. Dr. Green addressed the programmatics of the debate, noting that this mission is not THE life detection mission. Life metabolizes, reproduces, and evolves; such measurements can't be made remotely. Mars 2020 intends to investigate a past habitable environment and interrogate a sample for the presence of ancient life. Dr. Rummel concurred, adding that the instrumentation is not available and that a sterilizable rover is not affordable at this time. Dr. Green described Mars 2020 as a Decadal Survey-compliant mission that is the beginning of MSR. In response to some disagreement with the statement, Dr. Green observed that while a planetary Decadal Survey lays out objectives, NASA must construct missions to move objectives forward that align with budgets and international interests. Dr. Farley added that adaptive caching has been vetted thoroughly, and that the RSSB will be doing further work in addressing requirements for detecting definitive biosignatures. Dr. Doran said that the RSSB task seems to be ruling out bringing back extant life by virtue of its permissible temperature maximums.

Dr. Farley reviewed the Mars 2020 payload: MastCamZ, SuperCam, Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC) (fluorescence and Raman spectroscopy at thin-section scale), Planetary Instrument for X-ray Lithochemistry (PIXL), Radar Imager for Mars' Subsurface Experiment (RIMFAX) (with penetration to 50 meters maximum, very sensitive to brines and ice), Mars Environmental Dynamics Analyzer (MEDA), and the Mars Oxygen ISRU Experiment (MOXIE) (conversion of CO_2 to O_2). The Mars 2020 Project Science Group concluded that there is no way to plausibly confirm the existence of Martian life nor even a definitive biosignature, thus the rover's Raman spectrometer only has the ability to identify broad classes of certain organic molecules. The payload will be used to detect structures, classes of organic molecules, and chemical signatures. The biosignatures will be established upon return analysis.

Mars 2020 science requirements as to inorganic constituents are based on an exhaustive list of elemental contaminant limits, compiled in consultation with a community working group. The mission will be subject to total organic carbon and individual compound limits as recommended by the Organic Contamination Panel. Other sample quality factors are limits on things like induced fractures, maximum temperatures, and magnetic field characterization. The limit for total organic contamination is on the order of 10^5 microbial cells per sample, so limits on total microbial cell count (living and dead) will be determined, possibly limited to an order of 5 cells per sample, or through a thorough genetic inventory and contaminant archive to facilitate rejection of terrestrial hitchhikers. The limit of detection in rock is 100 (microbial cells) per square centimeter. The planetary protection requirement is to limit contamination to 1 cell per sample. With a detailed inventory of contaminants before launch, the mission will have round-trip witness blanks that will allow tracing of contamination that occurs during the mission. Dr. Lindberg commented that the mission is operating under the null hypothesis that life is not there. Dr. Steltzner noted that these mission requirements are for preserving science, and essentially represent the opposite of the PP null hypothesis.

Dr. Doug Bernard briefly addressed PP requirements for Mars 2020. The project Key Level 2 requirements are being developed, incorporating recommendations from both the OCP and the MSL Lessons Learned study. These include requirements similar to those developed for both InSIGHT and MSL, in the categories of: witness plates, blanks and archiving; special regions considerations; viable organisms; organic carbon; and PP categorization. With regard to special regions, driving PP requirements include the expectation that there will be an update to Category V for numerous elements in the rover.

Dr. Steltzner reviewed the spacecraft and its Sample Caching System (SCS), for which the main concern, and challenge, is the cleanliness of the returned sample, and which will require careful treatment of the hardware that sits in the sample handling enclosure. The samples are acquired by a set of coring bits; the sample tubes are taken out and placed into sterilized bits, put into the corer, and then drilled into an area of interest to obtain a core sample. The sample tube is a closed-end sterile item, which is placed into a sterile bit during operations; the filled tube is then taken out and sealed. The sample is held in place by a ball lock. The sample handling hardware is cleaned by placing it in an oven at 500°C, where it is fully oxidized. The sample tube remains sealed until it receives the sample. Tolerances are tight enough to thwart flow; there is a region of the tube in which air exchange occurs, but only at Stokes velocity. The design of the SCS takes into account forces coming from launch, entry, heat shield dynamics, depressurization and repressurization forces, etc. and their effects on the sample tube. Dr. Lindberg paraphrased by saying that the seal depends on fluid-mechanical barriers, and not hermetic seals. Dr. Steltzner noted that in the fluid mechanical barrier, the dimension of the gap is about half a millimeter, and made an analogy to a HEPA filter to describe the same kind of mechanics. The barrier can slow particles down to 0.5 micron in size. The gas environment during cruise phase is a vacuum. There is still outgassing during cruise phase, when one worries more about molecular contamination. Those are separate requirements that are based on standard practice for avoiding molecular contamination of optics. The biobarriers will of course be tested. The sample tubes are made of titanium, with a titanium nitride coating. Steel is used for the bit, and titanium carbide for the teeth. A caging plug is used to keep the sample from rattling around, caps seal the sample, and all of the above is sealed with a fluid mechanical biobarrier. Tungsten disulfide is used for lubrication. The nominal pressure for the caging plug maintains the pressure below the stress level of the return pressure (of an order of less than 50 newtons). The blanks see the whole process. Desire is to fit 6 blanks, surrogate materials in a sealed container.

Asked to address headspace issues, Dr. Steltzner described the requirement to collect 8 cc of rocky material (per sample tube), plus or minus 2 cc; design-wise, a sealing plug can practically meet the caging plug. Dr. Rummel asked how the thermal design of the rest of the rover is affected when the SCS breadbox is opened. Dr. Steltzner replied that the sample tubes are held at near-ambient temperatures. The current understanding is that the rover will drop the tubes at a single location that has been determined to be accessible for a follow-on retrieval mission. At present, maximum sample tube temperature is set at 50°C, which is expected to increase to 60°C.

The cleanest hardware is sterilized at 500°C for minutes. The least clean hardware is maintained at a cleanliness of 300 spores per square meter. On Earth, the seals prevent recontamination of the sampling tubes. On Mars, contamination transport modeling is being used to understand the recontamination threat. Mars 2020 believes this approach is consistent with the subsystem approach found in NPR 8020.12. Dr. Lindberg questioned whether the team was creatively applying the definition of a subsystem in order to comply with requirements. Dr. Steltzner denied that this was the case. Asked how testing for microbial loads was carried out, he replied that this was done by process, as per NPR 8020.12.

There are four contamination principles: the Mars 2020 sterilized subsystems will be maintained as sterile until needed for use in sample acquisition; the period and breadth of exposure to possible contaminants is to be minimized; minimize knowledge of system and contaminants needed to ensure contamination; and manage off-nominal risk by minimizing the contamination sources via design and material selection.

As to PP-specific hardware, the PP subsystem is the sample tube. The elements that are sterilized are biobarrier-protected to produce a category IVa spacecraft, with a very clean subsystem. The outside of the tube is exposed to the Category IVa spacecraft. Everything in the silo is sterile, but the outside of the silo is assumed not to be sterile by assembly, test, and launch operations (ATLO) phase. It is not possible to sterilize things that go to Mars and then test them thereafter; it is assumed that these exposed surfaces will no longer be sterile.

The fluid mechanical biobarrier (FMBB) used to seal the tubes is an ongoing engineering development, with testing planned. Asked where the performance standard came from, Dr. Steltzner cited NPR 8020.12 requirements, which necessitate cleaning an item to a verifiable (300 spore per square meter) level, and thereafter subjecting it to 4- and 6-log reduction techniques. Dr. Wadhwa felt that the blanks would also provide some reassurance about the validity of the transport analysis. Dr. Steltzner noted that the FMBB seal could be replaced with a HEPA filter, but this would increase the likelihood of getting the sample tube jammed. However, HEPA is still on the table for trade space. Dr. Rummel expressed concern about the open end of the tube being exposed to Category IVa surfaces.

Work continues on operational contamination assessment. The engineering team is analyzing and testing several different ways to dislodge a particle: viscously lifted off the surface, liberation by mechanical loads, and wind transport. Operationally, the mission will walk through the spacecraft by analysis, and by test-based models of physics of transport, just as MSL does.

Model validation includes testing in the areas of fluid mechanical suspension, adhesion of abiotic and biotic particles, and surface roughness analyses. Particulate development tests will include an FMBB demonstration by the first quarter of 2016. Testing is partially complete for biological and abiological wind and mechanical loads, with saltation experiments to be conducted in Calendar Year 2017. Molecular development tests include those for molecular transport to the sample tubes after firing at ATLO and the during cruise phase. Characteristics of outgassing against Tier 1 compounds will also be tested. Thus far the sample tubes are easily meeting 1 ppb limit in some testing. Biological-based development tests include assessing the fractions of airborne particulate with biological signatures, performing microbe-to-particle assessments on surfaces as well as spore-to-total viable organism (TVO) assessments, performing a genetic inventory for flight hardware, and determining microbial adhesion on surfaces. Peer and expert reviews to date have been extensive, supplemented by literature searches, board and institutional assessments, and communications with experts in the field. A concern raised by the Independent Assessment Review Board led by Dr.

Phil Christensen about the timing of planned tests, cost and schedule is now being incorporated into the project plan. The project is actively trying to accelerate testing to buy down risk, and is keeping the HEPA filter as a viable off-ramp. Cost and schedules have been updated. The project will be bringing the institutional and Christensen boards back to assess the project's response to concerns.

Dr. Steltzner presented results of BioVigilant testing of several cleanrooms at JPL, where data had been put through a worst-case transport analysis. Results suggest good margins thus far in terms of the requirement for operational transport analysis. Any subsystem approach creates a contamination gradient on Earth and at Mars during use. Mars 2020 is aiming to get to Phoenix-level cleanliness, which also used a FMBB. It is useful to look at an example of a Phoenix-like spacecraft configuration to determine how much transport occurs over the contamination gradient. This requires having a model for contamination during operation at Mars. The project is considering two models: one million viable organisms in the trench, vs. 0 viable organisms in the trench. These are plausible bookended examples, but the project recognizes that more science and engineering must be brought to bear on the situation. Extensive BioVigilant testing will continue, using a variety of physical conditions fed into the models.

Phoenix used a "bag and bake" approach to biological cleanliness, an approach that can't be used for Mars 2020 because it is budget-unfriendly. Studies indicate that a bakeout duration for Mars 2020 would be 240 weeks, in order to bake the handling arm and other components in the enclosure to maintain tube cleanliness. A Viking system-level bakeout approach to Mars 2020 is not possible due to the presence of electronics components, radiofrequency applications, small-scale semiconductors, and an MMRTG. These data are based on Sarah Gavitt's report on Mars System sterilization, commissioned by JPL. Dr. Rummel felt it important not to mischaracterize results of this report, saying that a Phoenix approach could actually be used, with some changes in design.

The estimate of the contamination gradient on MSL at launch was 20.5k spores (by PP test). The Mars 2020 requirement at launch is a total of 40k spores, encompassing 2000 spores on the turret and arm, and 600 spores in the sample handling enclosure. A rough estimate is that 80% of these will die during cruise phase. In addition, EDL wind cleaning will scrub the surfaces of the rover, combined with 7 months of hard vacuum, and dust storms and devils with velocities of 40-60 m/s. EDL wind magnitudes are known for the bottom, sides and top of rover. Given these numbers, remaining viable organisms (VOs) after EDL wind cleaning are calculated as 4.4×10^5 at top deck, 1.5×10^5 at sides, and 10^4 on bottom. Ultraviolet cleaning in the first three sols on the surface will also kill viable organisms, to an estimated 4.4×10^3 at the top deck, 9×10^3 on the sides, and 1×10^2 on the bottom. A gradient has also been calculated for the end of sol 2 for the sample handling enclosure.

Dr. Bernard presented data on the initial conclusions of a bounding meta-analysis being carried out for Mars 2020, which is intended to precede a more detailed analysis. Major contributors to contamination are VOs in the tube, VOs on Mars at sample location, VO transfer during rover operations, and VO transfer from the caching assembly during caching operations. VOs on Mars at the sampling location, after EDL and exposures to wind during commissioning, after increased wind close to sample location, and after VOs are released by unmodeled processes close to the sample location, all generally fall well below (2×10^{-6} to $1 \times 10^{-}4$) the requirement of 0.7 VO/m^2. Similarly, inside the caching assembly, VOs dislodged by wind, vibration, volume probe or by unmodeled processes during caching operations, must be below the requirement of less than 0.0001. Mitigations not yet taken to achieve this requirement include application of ultraviolet (UV) light prior to ATLO closeout, and application of UV at Mars prior to caching operations, or using a vapor hydrogen peroxide process for cleaning the caching assembly.

Two of the four contributors of VOs are deemed controllable by engineering processes. Analysis of Contributor 2 (VOs on Mars at the sample location) showed an expectation that adhesion-based resuspension models will demonstrate excellent margins, while further particle transfer test and analysis is being planned. The Contributor 4 (VO transfer from the caching assembly during caching operations) condition is dominated by assumptions on unmodeled particle "will" and could be mitigated by a number of means. Dr. Boston asked how big a burden it would be to the payload to add UV lamps. Mr. Wallace felt such an addition would be procedurally manageable prior to closeout, before launch. Bringing it along on flight would be a harder task, but it's not out of the question. Mr. Perry Stabekis commented that UV has been commonly used in cleanrooms during steps in assembly. Dr. Imperiale cautioned that some spores will be resistant to UV. Dr. Rummel felt that while there seemed to be a number of viable workarounds, he suggested that the team investigate more fully some areas where the system could be more robust. The team should also keep in mind that small-scale rough surfaces do provide some UV shadowing for microorganisms.

In terms of special regions, Dr. Bernard thought a meeting of minds would need to take place in order to formulate an achievable requirement. In the interim, the team has proposed an alternate requirement to replace the special regions PP requirement wording while meeting the intent. A Category IVb subsystem definition for MARS 2020 involves pre-sealing the sample tube, the caging plug and the sealing plug. Post-sealing, the Category IVb subsystem includes only those parts for the tube, caging plug and sealing plug interior to the effective location of the seal. Dr. Lindberg noted that it sounds as if the team is changing subsystem definition as it goes along, which does not seem tenable. Defining a subsystem as what you intend to clean is meaningless from the standpoint of an engineering requirement. Dr. Bernard explained that he was using the term subsystem in terms of that documented in NPR 8020.12. Dr. Lindberg felt that a more honest approach would be to ask for a waiver of the requirement and inform the PPO that a part of the subsystem will be clean. Mr. Wallace interjected that the project was not hiding behind anything, and was simply trying to provide a system-wide solution that meets Level 1 requirements as well as to provide information for transparency. Dr. Rummel said that any hardware that contacts the sample must be Category IVb as well; this consideration must be taken into account when determining what touches the sample. He did feel, however, that given the description, that the requirement could be met. Dr. Bernard agreed, adding that the project believes the design approach is implementable, represents acceptable risk, and will continue to work with PPO to address potential gaps and concerns.

Dr. Farley addressed the treatment of the blanks, which must be characterized for all the science objectives- scientific, biological and chemical. There are multiple vectors to worry about, such as the drill bits and tubes. He was most worried about things that are added in the form or particulates or vapor. The two strategies being considered are having a surrogate solid material in the tube, by drilling it into a blank material, or placing witness material in each tube, or in any vectors of contamination (without drilling). The RSSB will consider these options. From a science view, the project could do both, but was not sure of the practicality. The current desire is to obtain 31 returned tubes.

Public comment period

Abby Allwood of JPL commented that Mars 2020 must avoid a false negative situation, and asked if there were clear logic that underpins requirements on seeking biosignatures. She felt that the mission needed to have a very clear, widely subscribed-to scientific rationale.

Discussion

Dr. Onstott commented that the BioVigilant testing system is not very sensitive for submicron particle sizes. Dr. Steltzner understood this, and added that there is also a fundamental air suspension physics that tails off on larger-size particles. The testing involves getting data on both sides of the distribution. The transport model also incorporates electrostatic forces; van der Waals forces seem to predominate. All the various adhesive forces are also included. Dr. Onstott felt the project might want to take an approach to get to the 10^{-4} or 10^{-6} detectability level, and urged the project to design an experiment to validate a transport model. There was some disagreement as to whether any known viruses were stable enough to consider in the transport analysis model. Dr. Goeres recommended Isaac Flapper and Joe Seymour as consultants on further testing.

Findings and Recommendations Discussion

PPS discussed potential findings and recommendations.

Dr. Teplitz suggested that the presence of high-energy neutrinos, which can liberate photons or electrons that can cause mutations in biological systems, was a poorly understood contributor to putative conditions in a sample tube. He felt more data on this issue should be gathered, given potential implications for degradation of any samples left on the Mars surface or during cruise phase.

Dr. Rummel felt that there are no showstoppers that would keep Mars 2020 from being successful in implementing planetary protection. Dr. Imperiale agreed, saying that any prior concerns about sample sealing had been allayed. Dr. Lindberg noted that the project, given the constraints of the program, has been using new approaches, but that the burden remains with them to ultimately demonstrate to the PPO that the approach they have taken will demonstrably meet their requirements. Dr. Doran reiterated his confusion about the (lack of) life detection as a science goal. Mr. Wallace noted that when the samples come back, he expected that extant life experiments would be run on them. That is one reason to maintain the temperature of the sample, after coring, close to its indigenous temperature on Mars. Dr. Bernard said the science question has more to do with the sample's preservation of ancient life. Dr. Imperiale asked if the experiment were being set up properly: how does temperature selection square with this objective of detecting ancient life? Dr. Onstott noted that the presence of phospholipids in a sample may suggest ancient life forms. At Mars, if there is an ancient biosignature, one may have to rely more on contextual cues, which will require a detailed organic analyses plus context. Will Mars 2020 collect a sample in the hope of finding Martian life that can live in brines, and survive radiation? Dr. Lindberg commented that the operational protocol would be to avoid such an area because the rover would not be clean enough to contact special regions, and could also be warm enough to induce a special region. Furthermore, the sampling setup cannot handle fluids. Dr. Boston was concerned about the discussion on blanks, which she felt include, ideally, a positive control and a negative control (empty tube). Mr. Wallace agreed but recognized that the project has to optimize its limited resources.

PPS concurred on delivering an observation; i.e. there are no showstoppers to the Mars 2020 project's successful compliance with PP requirements. The subcommittee also concurred with the recommendation that the PPO adopt the language of the COSPAR Colloquium results on Mars Special Regions and Icy Bodies.

PPS also made an observation that welcomed the increased emphasis on a detailed planetary protection protocol for daily operations on Mars and looked forward to the final product. Dr. Lindberg asked Dr. Conley to obtain permission to transmit Dr. Grunsfeld's relevant email to members of the PPS.

Dr. Rummel suggested that PPS recommend the development of materials that are more easily sterilizable so that spacecraft can visit the wettest, warmest areas on Mars, and that PPS might recommend to the PSD that they support develop instruments that can be system-level sterilized. In addition, PSD might pursue an NRC study to look at the sterilization of instruments and potential roadblocks, in the context of the planned Europa mission. Human Exploration should care about this issue as well. Dr. Onstott agreed to write this recommendation with Dr. Rummel's additions.

Dr. Boston requested a briefing from STMD that focuses on PP technologies. Dr. Lindberg agreed to add this to a list of agenda items.

Dr. Goeres described how antimicrobial surfaces are assessed in terms of attachment rates, and ease of cleaning, with the phrase "time to failure" used as a metric in biomedical applications. These materials don't have the most stellar track record, as they often fail in piping and engineering systems. She felt it was not impossible to adopt such coatings for PP but was setting the caveat to have good methods in place to test for longevity. It might be possible to use radiation or temperature extremes to decontaminate surfaces. Dr. Imperiale added that these materials could also be toxic (constrained for medical applications, obviously). Dr. Lindberg agreed to add this to the discussion at the June meeting, and added that JPL, Ames, Goddard and Langley might be appropriately tasked to assess such materials. The Defense Advanced Research Projects Agency

(DARPA) the Department of Defense (DoD), the Department of Homeland Security (DHS), and a recent White House letter on biosafety were also cited as sources for ideas.

Dr. Lindberg presented a certificate of appreciation to Dr. Rummel, recognizing his long history of contributions to planetary protection, and marking his last meeting with the PPS as an official member.

Dr. Kaminski made some wrap-up comments. Dr. Lindberg adjourned the meeting at 3:59 pm.

Appendix A
Attendees

Planetary Protection Subcommittee Members
Robert Lindberg, University of Virginia, *Chair PPS*
Penelope Boston, New Mexico Tech
Colleen Cavanaugh, Harvard University
Peter Doran, University of Illinois, Chicago
Darla Goeres, Montana State University
Michael Imperiale, University of Michigan
T.C. Onstott, Princeton University (online)
John Rummel, East Carolina University
Nick Steneck, University of Michigan
Meenakshi Wadhwa, Arizona State University

U.S. Agency Representatives to the PPS
Kelvin Coleman, Federal Aviation Administration
Vigdor Teplitz, Department of State

International Space Agency Representatives to the PPS
Vicky Hipkin, Canadian Space Agency (online)

Catharine Conley, *Planetary Protection Officer*, NASA HQ
Amy Kaminski, *Executive Secretary PPS,* NASA HQ

NASA Attendees
Abby Allwood, NASA JPL
Louis Barbier, NASA HQ
Doug Bernard, NASA JPL
Will Brinkerhoff, NASA GSFC
L. Cooper, NASA JPL
Elaine Denning, NASA HQ
Therese Errico, NASA GSFC
Ken Farley, NASA JPL
T. Jens Feeley, NASA JPL
James Green, NASA HQ
Julia Goyla, NASA JPL
Doug Isbell, NASA JPL
Gordon Johnston, NASA HQ
Melissa Jones, NASA JPL
Fuk Li, NASA JPL

John McNamee, NASA JPL
Orlando Melendez, NASA HQ
Betsy Pugel, NASA HQ
Christy Rivera, NASA JPL
Mitch Schulte, NASA
Elaine Seasly, NASA LARC
Betty Siegel, NASA HQ
Gary Smith, NASA
Adam Steltzner, NASA JPL
Jennifer Stern, NASA GSFC
Ellen Stofan, NASA HQ
Ashwin Vasavada, NASA JPL
Mary Voytek, NASA HQ
Matt Wallace, NASA JPL
Jim Watzin, NASA HQ
Ken Williford, NASA JPL
Dan Woodard, NASA HQ

<u>Non-NASA Attendees</u>
Sara Barber, U.S. House of Representatives
Brian Blakkolb, Johns Hopkins University Applied Physics Laboratory
Amber Charlesworth, U.S. State Department
Bill Hurowitz, Stonybrook University
Tony Reichhardt, *Air and Space* Magazine
Andy Spry, SETI Institute
Perry Stabekis, retired
Pamela Whitney, U.S. House Committee on Science Space and Technology
Ana Wilson, Zantech IT
Joan Zimmermann, Zantech IT

Appendix B
Committee Membership

Robert Lindberg (Chair)
University of Virginia

Catharine Conley, Planetary Protection Officer
NASA Headquarters

Amy Kaminski, Executive Secretary
NASA Headquarters

Penny Boston
New Mexico Tech

Colleen Cavanaugh
Harvard University

Peter Doran
Louisiana State University

Joanne Irene Gabrynowicz
University of Mississippi School of Law

Darla Goeres
Montana State University

Michael Imperiale
University of Michigan

Tullis Cullen Onstott
Princeton University

John D. Rummel
Department of Biology
East Carolina University

Nicholas Steneck
University of Michigan

Meenakshi Wadhwa
Arizona State University

Agency Representatives:

Kelvin Coleman
Federal Aviation Administration

Dale Griffin
United States Geological Survey

Victoria Hipkin
Canadian Space Agency

Gerhard Kminek
European Space Agency

Vigdor Teplitz
Department of State

Michel Viso
CNES/DSP/EU

Subcommittee Administrative Support:

Ann Delo
NASA Headquarters

Appendix C
Presentations

1. Planetary Science Division Overview; *James Green*
2. Planetary protection issues and updates; *Catharine Conley*
3. MSL Gale Crater Observations; *Ashwin Vasavada*
4. Mars Exploration Program Overview; *James Watzin*
5. Returned Sample Science Board; *Harry McSween*
6. COSPAR Colloquium Report on Mars; *Victoria Hipkin*
7. COSPAR Planetary Protection for Icy Worlds; *John Rummel*
8. PPWG Fact-finding Report; *Robert Lindberg*
9. Mars 2020 Planetary Protection Requirements; *Catharine Conley*
10. Mars 2020; *Adam Steltzner, Ken Farley, Doug Bernard*

Appendix D

NASA Planetary Protection Subcommittee
Meeting Agenda
December 8-9, 2015

December 8, 2015

8:30 am	Welcome, orientation, introductions	Amy Kaminski, NASA HQ
8:40 am	Words from the Subcommittee chair	Robert Lindberg Univ. of Virginia
8:55 am	Discussion with Science Mission Directorate Associate Administrator	John Grunsfeld, NASA HQ
9:25 am	Planetary protection issues and updates	Cassie Conley, NASA HQ
10:10 am	Break	
10:25am	Planetary Sciences Division update	James Green, NASA HQ
11:10 am	Mars Exploration Program update	James Watzin, NASA HQ
11:55 am	Subcommittee discussion	
12:15 pm	Lunch	
1:15 pm	Planetary Protection Working Group meeting report-out	Robert Lindberg Univ. of Virginia
2:00 pm	COSPAR updates	Victoria Hipkin, Canadian Space Agency John Rummel, McGill Univ.
2:45 pm	Break	
3:00 pm	MSL Gale Crater observations	Ashwin Vasavada Jet Propulsion Laboratory
3:45 pm	Mars 2020 planetary protection requirements	Cassie Conley, NASA HQ
4:30 pm	Public comment period	
4:35 pm	Subcommittee discussion	

5:00 pm	Adjourn for the day	
6:15 pm	Subcommittee dinner	

December 9, 2015

9:00 am	Welcome	Amy Kaminski, NASA HQ
9:05 am	Words from the Subcommittee chair	Robert Lindberg Univ. of Virginia
9:15 am	Returned Sample Science Board	Harry McSween Univ. of Tennessee, Knoxville
10:00 am	Break	
10:15 am	Mars 2020	Ken Farley, Jet Propulsion Laboratory Adam Steltzner, Jet Propulsion Laboratory Doug Bernard, Jet Propulsion Laboratory
12:15 pm	Lunch	
1:15 pm	Mars 2020 (continued)	
2:30 pm	Public comment period	
2:40 pm	Subcommittee discussion/recommendations	
4:00 pm	Adjourn meeting	