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Planetary Protection Subcommittee

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NASA Headquarters
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MEETING MINUTES

Robert Lindberg, Chair

Amy Kaminski, Executive Secretary

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June 1, 2016 (Day 1)

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.

Dr. Lindberg welcomed members of the subcommittee, and offered some thoughts on the previous meeting, which had produced two recommendations and two findings. The first recommendation, that NASA's Office of Planetary Protection embrace the new draft COSPAR guidelines on Mars Special Regions and water worlds such as Europa, was transmitted to the Science Mission Directorate (SMD) Associate Administrator (AA) and accepted. The second recommendation, that NASA invest in technologies to enable sterilization of instruments necessary to seeking life at Mars and other bodies, was put forth in light of the fact that technologies for reducing bioburdens to a level of cleanliness sufficient for life detection protocols have not advanced sufficiently to date. This latter recommendation was transmitted to the Science Committee (SC), and subsequently sent to the NAC and to NASA. PPS also made an observation on the planetary protection (PP) approach to the Mars2020 (M2020) mission in development; i.e. PPS saw no undue obstacles to achieving PP requirements, but there was still work to be done. PPS made a second observation on new SMD tasking to the Mars Science Laboratory (MSL)/Curiosity to better track day-to-day operations on Mars, and was pleased to see this action going forward. Dr. Lindberg noted that there have been some changes at NASA. SMD AA Dr. John Grunsfeld has retired, and Mr. Goeff Yoder is acting AA.

Dr. Lindberg reported he had had discussions with the Planetary Science Subcommittee (PSS) to plan for a one-day joint meeting, in order to share topics of interest to both subcommittees, such as exploration of water/icy worlds. Dr. Peter Doran raised the topic of SpaceX's planned exploration of Mars. Dr. Lindberg reported a potential conflict of interest due to his work with Moon Express Inc. and how NASA will interact with PP aspects of commercial missions, and announced that he would recuse himself if necessary, noting that the topic is important to consider on future agendas.

Planetary Protection Update

Dr. Cassie Conley, Planetary Protection Officer (PPO), gave an update on PP issues in the context of NASA's strategic goals, which is expanding human presence into the solar system. The Journey to Mars is squarely in the sights for PPS, as are plans for robotic exploration of asteroids and other bodies of interest, and the activities of the International Space Station (ISS) and its research in enabling future human and robotic presence in space and returning objects to earth.

PP policy is embodied in the NASA Policy Document (NPD) 8020.7G, and the PPO acts on behalf of the AA for SMD to maintain and enforce the policy. The National Academies Space Studies Board (SSB) provides recommendations to NASA on PP requirements for specific bodies and mission types. NASA's requirements for robotic missions are documented in NASA Policy Requirements (NPR) 8020.12D, and requirements for human missions are documented in NASA Policy Instruction (NPI) 8020.7, "NASA Policy on PP Requirements for Human Extraterrestrial Missions," released in May 2014. Dr. Lindberg noted that NPI 8020.7 had been written as a response, in part, to prior recommendations from PPS.

Dr. Conley noted that the scope of the PPS includes programs, policies, plans, hazard identification and risk assessments, and includes consideration of policy documents and organizations. Dr. Conley stated that the PPS reviews and recommends appropriate PP categorizations for all bodies of the solar system to which spacecraft are sent, and the scope also includes PP technologies, systems and capabilities, and recommendations for providing long-term improvements in future operational systems to support PP.

Dr. Conley proceeded to review previous PPS recommendations and their outcomes. In November 2014, PPS recommended that communication be improved between the PPO and MSL project on *in situ* operations on Mars, as well as to improve PP input into NASA's assessments of launch and reentry license applications to the Department of Transportation (DoT) and the Federal Aviation Administration (FAA) by nongovernmental entities. These recommendations have been taken up, and Dr. Conley was happy to report that responsive efforts were ongoing. PPS also observed in November 2014 a concern about the reporting line of the PPO as being consistent with responsibilities to assure treaty compliance across the directorates. Dr. Conley noted that the PPS might want to re-address this issue in light of current plans for commercial activities in space. In June 2015, PPS recommended that the Mars 2020 mission be classified as a Category V, restricted Earth return mission. In December 2015, as outlined in Dr. Lindberg's opening remarks, the two recommendations from PPS were adopted in full.

The Cassini-Huygens mission is approaching its end and will deorbit into Saturn over the next two years. From a PP standpoint, the only concern at Saturn is Enceladus. The mission's ability to control the spacecraft, with respect to the risk of Enceladus impact, seems unchanged; no micrometeorite impacts have been seen thus far. The performance of the mission is a tribute to excellent operational management of the mission, and a highly reliable operational system. The mission will undergo another review the second week of June.

In New Frontiers, the category II New Horizons mission science team has identified another target object beyond Pluto, where it has been determined that there is no expectation of concern in contaminating objects in the Kuiper Belt. The category II mission, Juno, will be inserting into orbit around Jupiter on 4 July. The project recently doubled the length of its orbital period, which slightly increased the likelihood of spacecraft impact into Europa.

Reliability of operations was considered acceptable, and the mission remains in compliance with PP. The category V unrestricted Earth return mission, Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx), has no PP constraints on the Earth-return leg of the mission (September 2016 launch, 2018 arrival at asteroid Bennu). Dawn at Ceres, a category II mission, is considered to have minimal risk of impact on Ceres due to orbital mechanics constraints. Asked about risk at Ceres, Dr. Green felt there were few PP risks due to the low risk of impact, but that there is believed to be a cryovolcano at the center of Occator crater, fueled by a water-ice process. Dr. Conley reiterated that Dawn remains a category II mission, with the constraint that the mission provide evidence that there will be no contact with a habitable environment. Other missions under PP assessment include phase A selections VERITAS and DAVINCI at Venus, Psyche (metallic asteroid), Lucy (Jupiter Trojan asteroids), and a Near-Earth Object Camera.

The flight-delayed mission to Mars, Interior Exploration using Seismic Investigations Geodesy and Heat Transport (InSight) spacecraft has been partially disassembled and put into storage in anticipation of a 2018 launch. The MarCO (Mars Cubesat One) cubesats associated with the mission are also being stored. The PPO is in ongoing discussions with the mission to ensure that the spacecraft(s) stays within the required levels of bioburden during the storage period; evaluations and interactions are going well. Dr. Lindberg observed that now is a good time to develop and document processes for maintaining cleanliness in storage, which NASA can accomplish by recording its procedures as a Lessons Learned exercise. Dr. Green noted that the spacecraft will re-enter Assembly, Test, Launch and Operations (ATLO) with a new set of assays to re-demonstrate cleanliness. Dr. Lindberg added that a future agenda should include a briefing from the InSight team on the status of the spacecraft pre- and post- storage.

Ongoing PPO activities include the adaptation of Mars Science Laboratory (MSL) Lessons Learned recommendations, ensuring appropriate requirements flowdown in Mars missions, revising and coordinating PP documentation, and expanding training options. Cross-directorate coordination continues in this area, with expanding interactions with the Office of Safety and Mission Assurance (OSMA), Human Exploration and Operations Mission Directorate (HEO), and the Space Technology Mission Directorate (STMD). A charter to stand up a new PP Coordination Group has been developed to facilitate these interactions. The PPO sets planetary protection policy and requirements that NASA missions then implement, which the PPO then verifies. Dr. Conley noted that she does not have adequate staffing to fulfill the PPO's duties. In other areas, the PPO was working closely with missions, active and in development, including MSL, M2020, InSight, the Mars Atmosphere and Volatile Evolution (MAVEN), the Mars Orbiter Mission (MOM; India Space Research Organisation), Mars Reconnaissance Orbiter (MRO), Cassini, Dawn, New Horizons, Juno, Europa, and commercial space. Dr. Conley stressed that SpaceX is committed to U.S. obligations for PP, and that the company had been actively communicating with NASA for a number of years, but thus far communications have not included any discussion of Mars sample return. PPO is also adding to its portfolio the Launch Services contracts for cubesats.

Dr. Conley noted that the Capability Development Risk Reduction briefing STMD gave at the recent NASA Advisory Council (NAC) meeting had contained no PP element. Dr. Lindberg added that twice now, PP has not been a specific topic for STMD despite PPO efforts to get PP technologies integrated into STMD roadmapping. The PP budget, at roughly $2.5M, is not decreasing but programmatic needs are increasing. Proposals to the PP research program in the ROSES 2015 call are still under review. The new ROSES 2016 will be delayed by 4-6 months. Dr. Michael Imperiale remarked that the 2015 proposals would be obsolete by the time of their selection, and felt that PPS should recommend more resources for the PPO. Dr. Darla Goeres asked Dr. Conley to comment on her ideal vision for PP training. Dr. Conley explained that current training modules range from 1-2 hour tutorials to half-day seminars, to an intensive 3-day training course with a laboratory element. Courses are offered to the general public as well as to practitioners. Dr. Conley reported efforts to set up a certification program for the latter. She felt it would be ideal to continue to offer a full range of self-taught, online courses as well as detailed lectures for the professional.

Planetary Science Division

Dr. Green presented a status of the Planetary Science Division (PSD). PSD has numerous instruments on foreign missions, and is working with Japan's Hayabusa 2 comet mission on sample-sharing and navigation, as well as providing navigation assistance to MOM. NASA continues to coordinate with ESA on Mars Express and ExoMars. Dr. Green noted that InSight, now launching in 2018, will include the release of the MarCO cubesats that will fly past Mars as InSight goes through Entry Descent and Landing (EDL), and will provide data back to Earth. NASA is preparing to position MRO and Mars Odyssey as well for additional support in data relay. ESA's ExoMars 2016 Trace Gas Orbiter will reach Mars orbit in September of this year. The US has a relay sensor on the Trace Gas Orbiter. Dawn is currently orbiting Ceres, having temporarily lost a reaction wheel; the project used fuel sparingly until the reaction wheel was re-started and now anticipates that Dawn will run out of fuel in late 2017 or early 2018. They are proposing an extended mission to the Senior Review and are looking at a variety of options.

As discussed, Cassini will make close flybys between ring and cloud tops of Saturn between now and mission termination. The risk of impacting Enceladus is vanishingly small and getting smaller. Cassini will be entering a highly elliptical orbit (pericenter orbit between rings and planet; apocenter at about 20 Saturn radii), before ditching into Saturn in September 2017. Juno is also in a highly elliptical orbit, but its pericenter will be within 5000 km of the planet's cloud tops. Juno is now within the gravitational sphere of Jupiter. On 20 July, NASA will be celebrating the 40th anniversary of the Viking missions. On 8 September, OSIRIS-REx will launch to the carbonaceous chondrite asteroid, Bennu. After arrival in 2018, the spacecraft will stay at Bennu almost two years, carrying out detailed mapping and gravity measurements. The spacecraft will use a touch-and-go system to acquire samples, using three opportunities to do so. The spacecraft can accommodate as much as a kilogram of sample, while the requirement is about a tenth of that. The sample will return to Earth by 2023.

Within the Discovery program, Dawn and the Lunar Reconnaissance Orbiter (LRO) are still operating and in Senior Review. The Strofio instrument is being delivered to the Italian Space Agency for a January 2018 launch of Bepi-Colombo. Discovery selections have been made, with downselects to be made in 2018. In the New Frontiers program, New Horizons is in Senior Review, while its data download will be complete by September. The spacecraft is now targeted to another Kuiper Belt Object (KBO), and has already carried out the burn maneuver that will allow the spacecraft to get there. If approved, the spacecraft will reach the next object on 1 January 2019. The next Announcement of Opportunity (AO) for New Frontiers is January 2017. PSD has issued a community announcement, and a draft will be released in July/August 2016. The categories include comet surface sample return, ocean worlds, and a Saturn probe, with a launch readiness date (LRD) of 2024.

The Europa mission in development continues to progress in its objectives to study the ice shell and ocean, and composition of the moon, along with performing high-resolution imaging to identify a potential landing site. Instruments have been selected and an 18-member Science Definition Team (SDT) has been stood up for a lander study, as per Congressional direction, to prioritize science objectives and mission design. The lander objectives will include the capability to identify biomarkers and signs of extant life, and to assess the habitability of Europa via *in situ* techniques. NASA issued a NASA Research Announcement (NRA) for Concepts for Ocean Worlds Life Detection (COLDTech; for instruments for life detection at icy bodies) in May 2016 that will be followed by a lander AO at a later date. The hope is to mature technologies to be able to select instruments for flight when the time comes. Dr. Green expected the Europa lander SDT to comment on the necessary PP aspects, through the agency of a PP lead at the Jet Propulsion Laboratory (JPL).

PSD has also created a Planetary Protection Technology Definition Team to delineate the PP processes and techniques available to meet future PP mission requirements, and catalog materials and components compatible with PP protocols. The team will report out in November, followed by a ROSES call in February 2017 to invest in the necessary technologies. Dr. Lindberg thanked Dr. Green for responding so quickly, and noted that there is parallel PP activity at ESA via the PPWG. He urged Dr. Green to compare notes with them to avoid duplication of effort.

Dr. Green reported that PSD is planning to charge the National Academies planning with a mid-term review, to be tasked by September 2016, to produce a final report in December 2017. Many other recent reports can be fed into the mid-term review as well, in preparation for the next Planetary Decadal Survey (2023-2032), to be tasked before October 2019. Dr. Lindberg noted that there is a misconception that Special Regions are not explorable. Dr. Green concurred, noting that PSD is trying to increase its research and analysis (R&A) line to accommodate sterilization techniques that will allow exploration of Special Regions. He also acknowledged that Congressional attention, via COLDTech, is greatly helpful to the entire cause.

Discussion

Dr. Imperiale expanded on his previous thoughts, reiterating concern over lack of resources that are hindering the ability of NASA to carry out critical PP research. More research will support useful ideas and get them moving along more rapidly as NASA develops new missions. Dr. Goeres suggested that NASA establish an internship in the PP office, to assist with such items as developing training materials. Dr. Conley agreed, but added that the time and effort associated with an "office of one" is still insufficient for NASA-wide PP needs. Dr. Lindberg reminded PPS that recommending more resources requires the need for offsets: where does one want to spend less? That said, there is also Space Grant funding for undergraduate (summer) internships. Dr. Goeres suggested put together a proposal review committee composed of PPS members to help with the situation. Dr. Conley said the problem remains that there are too many responsibilities for one individual, and that at least another civil servant is required. Dr. Imperiale felt that the low budget of the PPO reflected an undervaluation of the position, and that it was better to invest now than to have an overburdened PPO later. Dr. Goeres and Imperiale agreed to draft a recommendation on this item.

Dr. Goeres asked if there were any reason to follow up on a previous PPS recommendation on the PPO reporting chain. Dr. Conley felt it would be appropriate. Dr. Lindberg indicated that the initial response from NASA on the PPO needing a certain level of independence and reach, particularly in regard to HEO at the time of the initial discussion, was agreement in part, but NASA felt that PPO should remain in SMD for the time being. It might be interesting to bring up the subjects at a time of transition of the SMD AA. Dr. Lindberg suggested keeping the idea on the watch list. Dr. Doran commented in closing that the PPO position within SMD and commercial efforts in space are separate issues, but they are connected by relevance.

The following items were discussed for adding to future PPS agendas:

- PP for commercial missions
- Update on updating PP requirements for humans
- Briefing from InSight; cleanliness in and out of storage
- Briefing from the Mars Exploration Program (MEP) on revisions to PP documentation from MSL Lessons Learned
- Update from Dr. Conley on PP training
- Briefing from Dr. Conley on ROSES selections
- KBO to be visited by New Horizons, pending outcome of Senior Review
- How NASA and FAA interface on commercial launches (as part of PP for commercial missions)

Mars Exploration Program Update

Dr. Michael Meyer, Lead Scientist for the Mars Exploration Program (MEP), presented an update on activities at Mars. He began by noting that NASA has benefited from both luck and skill at Mars, and the interaction between orbital and surface missions. Data collected at Mars, to date,

has led to the conclusion that early on, Mars was habitable, and capable of supporting life. Mars Express, the MAVEN, MRO, and the Mars Explorer Rover (MER) Opportunity, Mars Odyssey, and the MSL Curiosity rover are operating well. NASA continues a strong collaboration with India's Mars Orbiter Mission (MOM), and ESA's Mars Express, Trace Gas Orbiter and ExoMars Rover programs. Recently, NASA's InSight mission was postponed until 2018, while ESA's ExoMars was postponed from 2018 to 2020. A new United Arab Emirates (UAE) mission, HOPE, is planned for the 2020 timeframe. The state of the MEP is healthy and productive. MAVEN has completed its prime mission and is now in an extended mission. Similarly, Mars Odyssey continues its extended mission to provide thermal imagery and data relay services. Opportunity continues to provide ground truth data, having recently scaled Knudsen Ridge to investigate "red zones." MRO is still providing reconnaissance imaging and mineralogical mapping, Curiosity has completed two Mars years at Gale Crater, and ESA's Mars Express continues to operate NASA's two instruments, a deep radar sounder a space plasma and energetic atom analytical device. Mars 2020 (M2020) is on track and proceeding well. Two NASA Electra payloads on ESA's Trace Gas Orbiter are on the way to Mars, while the NASA Mars Organic Molecule Analyzer (MOMA) instrument is still in development for the delayed ExoMars rover.

Recent data at Mars have shown evidence of early morning cloud formation and frosts. Opportunity's view of the Sacagawea pan has shown features indicating Noachean terrain, and major clay and mineral formations, and should prove to be scientifically interesting. Recent observations have also revealed high concentrations of sulfur and manganese, showing interaction with water. MRO is celebrating 10-plus years of operation, providing data from the HiRise camera and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) spectrometer, showing the morphological and compositional character of the surface. MRO's Shallow Radar (SHARAD) instrument has detected enough CO_2 ice buried in Mars's south polar cap to double the concentration in the atmosphere (were it to be released). Measurements have also hinted at the internal stratigraphy of polar caps and their correlation with obliquity cycles, and shallow water ice has been detected at tens to hundreds of feet from surface. Seasonal flows are being seen in the central mountains of the Hale Crater. The Curiosity rover just finished a campaign at Bagnold Dunes, where it detected one whole (mid)wavelength not seen on Earth; this discovery poses a good physical problem. The rover is still in the Murray formation and is heading toward hematite and clay units, where it will continue to recording the history of the climate change process. Dr. Meyer noted that a MAVEN video of streaming ion had won an award for communicating science.

M2020, a Mars rover in development that is based on the Curiosity architecture, is taking advantage of heritage hardware and well on its way to completion. The M2020 mission is designed to give a geologic context at Mars, answer astrobiological questions, perform in situ resource utilization (ISRU) demonstrations, and pave the way for Mars sample return (MSR). A Key Decision Point-C (KDP-C)(confirmation review) for M2020 was held on 27 April. The rover will possess terrain-relative navigation (to be developed in collaboration with STMD), which will allow the mission to pick some landing ellipses that contain hazards, and will enable the rover to

go to rougher terrain and more interesting geological settings. There will also be a microphone on board. One mission objective is to operate more autonomously, efficiently and quickly on the surface. A helicopter technology demonstration has also been proposed for M2020 and is being tentatively considered. The helicopter would also carry a Go-Pro-like camera and be designed to carry out 5 demonstration flights. The concept is to keep it away from the rover, and will use a "cradle" or "holster" that will carry the helicopter away from rover before flight. It will communicate with the rover wirelessly. A decision to deploy the demonstration will be made by the time of the Critical Design Review (CDR). The blades are about a meter long, and the helicopter weighs about a kilogram. The mission is now doing untethered tests in a chamber simulating Mars atmosphere. Dr. Lindberg asked whether there would be separate PP requirements for the helicopter. Mr. George Tahu noted that MEP hasn't had a direct conversation with PP yet, adding that the device would be part of the rover when it lands. Dr. Conley said such a demonstration will likely have a "hard impact" requirement.

The strategic view forward for the M2020 mission and its payload center on the mission's role as part of the MSR campaign, the highest priority of the most recent planetary decadal survey. It is thus time to consider addressing the aging orbital assets at Mars and MEP is now planning to revitalize relay capabilities for future Mars missions. This will entail refreshing the infrastructure, increasing science investigations, providing continuity of high-resolution imagery and relevant remote sensing capabilities, as well as providing essential orbital support for sample return, as well as exploring solar-electric propulsion (SEP) to provide energy for capture capabilities, breaking the chain of contact, and supporting the reconnaissance of Mars satellites.

Dr. Goeres asked what percentage of the MEP budget was devoted to PP. Dr. Meyer replied that there was no specific percentage, as PP is not a separate activity. Dr. Conley noted that the cost estimate of PP for MSL was $12M out of a roughly $2.5B mission. By comparison, PP costs for Viking in today's dollars, were about 10% of the total mission cost. For estimates on retrofitting an MER for PP, the cost is about $60M in 2005 dollars. Dr. Lindberg commented that for PP efforts to improve from MSL cleanliness to Viking-level cleanliness, it would require roughly the cost of one instrument on a typical NASA mission.

Dr. Meyer provided the timeline for the next orbiter, which is planned to arrive at Mars when Odyssey is 22 years old, and MRO is 18 years old. MEP is building a Discovery-class core vehicle that can be adapted for an orbiter mission and is capable of operating in deep space, and designed for long life and autonomous operations.

In PP related activities, MEP has adopted a MSL/Curiosity operations protocol, drafted a charter to consider the likelihood and nature of special regions at Gale Crater, and is standing up a PP Technology Definition Team, as outlined by Dr. Green in the PSD presentation. The Technology Definition Team will probably not report out quickly enough to be useful for M2020, but will help to inform future ROSES calls for developing PP technologies and several different calls out of the SMD Research and Analysis (R&A) program. Anticipated tasks for the team are: to gather

and review recent observations and studies at Mars to determine the degree of confidence needed for determining the presence of modern special regions at Gale Crater.

Mars Science Laboratory (MSL) Curiosity Update

Dr. Ashwin Vasavada provided an update on the Curiosity rover. After two years of meteorology on the surface of Gale Crater, no frost or seasonal hydration of the soil has been detected, although relative humidity (RH) values can reach 70% at 1.6m above the surface, potentially saturating the ground where the temperatures are colder. Asked how temperature measurements were calibrated given the warmth of the rover, Dr. Vasavada reported that computation fluid dynamics models were used that took into account the effect of radioisotopic heat sources, indicating little effect of heat, given the location of the meteorology instrument mast. The rover continues to image potential slope activity; thus far the ChemCam instrument has imaged 7 HiRISE locations and an additional slope that will be visible for the remaining traverse. Recurring slope lineae (RSLs) are confirmed by multi-year behavior, not appearance. Curiosity will continue to gather data and compare to HiRISE results and search for RSL-like evolution of these features. Curiosity is no closer than 2-3 km to any of these features at present. The rover can only detect perchlorates when it is within 5m of a source, with the laser in active mode. There is no near-infrared spectrometer on Curiosity; it is assumed that orbital assets can try to make near-IR measurements, but the signal resolution would not be high. Dr. Imperiale asked how long to Curiosity would take to traverse the canyon. Dr. Vasavada said MSL hoped to reach site 46 in roughly 3 years, according to a Senior Review proposal. The minimal distance from any potential RSL will be between 2-3 km, unless a deviation is chosen. Site 46 has not shown RSL characteristics, to date.

In January 2016, the MSL project began using a newly developed protocol in daily rover operations to formally ensure that the rover is in compliance with its PP categorization. The protocol responds to the MSL PP categorization, criteria for special regions as per NPR 8020.12D, and direction from former SMD AA Dr. John Grunsfeld. Under the new protocol, a Surface Operations Working Group (SOWG) Chair, defined as the scientist on duty for a given day of operations, uses his or her expertise to identify gullies, bright streaks associated with gullies, and other features associated with the potential presence of water, and consults with other project scientists on shift, particularly the Surface Properties Scientist, regarding any features of concern. If potential special regions are identified, arm and surface activities are precluded and a special regions team is convened to assess the feature of interest before arm and surface activities can continue. If no such features are found, operations proceed, and the Chair reports and documents the reasons the potential special regions were noted as being absent. At the Activity Plan Approval Meeting, a Tactical Uplink Lead will poll the SOWG Chair as to whether the operations plan is "cleared" or "not cleared" for PP. There have been 4 instances thus far in which a report has been made, but the team has not yet had to preclude any activities. If in the future a Special Regions Team (comprised of the MSL Program Manager and Scientist, JPL PP Representative, and MSL science team members with expertise in geology, climatology and astrobiology) concludes that a feature is indeed a special region, the summary

of data supporting the decision will be sent to the JPL program office, the Headquarters MEP Director, and the PPO, upon which further discussions will be held between the Project, Program and PPO representatives to determine next steps.

Dr. Lindberg commented that the protocol seems not to rigorously disprove the presence of water. Dr. Imperiale asked whether the team was using the precautionary principle or not. Dr. Vasavada noted that while rover observations cannot rigorously disprove the presence of liquid water, MSL takes the protocol seriously and has had some very involved discussions, while using as much expertise as possible. Dr. Betsy Pugel asked about wheel trenching and any subsurface uncertainties. Dr. Vasavada replied that if there is no obvious surface indication before a traverse forward, the team would have to examine any subsurface contact after the fact. That said, there have been no indications, thus far, of water below the surface. All SOWG Chairs have been trained in the new protocol. Dr. Lindberg commented that one of the recent recommendations PPS had made to the PPO was to adopt the COSPAR guidelines regarding special regions on Mars. He added that the recently adopted protocol notably does not include consideration of evidence of methane spikes, which were included in the revised COSPAR definition. Dr. Meyer said that operationally, it is not clear what MSL can do about methane spikes unless they occur again, adding that there is no implication in the newly adopted protocol that would allow Curiosity to directly contact a special region.

Dr. Vasavada briefly reviewed the 4 case studies of special region considerations, and the images associated with them.

Discussion

Dr. Goeres asked if Dr. Conley had been included on the PP Technology Definition Team (PPTDT). Dr. Meyer replied that she had been part of the discussion, but that the team had not yet convened. The PPTDT will include individuals with experience in microbiology, spacecraft, and pharmaceutical technologies. Dr. T.C. Onstott commented, with respect to methane, that one obstacle appeared to be the long integration time required to detect its presence. Dr. Meyer agreed, noting that methane results are not instantaneous, and the project tends to discover the measurements several days after they have been made. Dr. Vasavada added that despite having increased the frequency of sampling during operations, there has been no detection of another methane spike. Dr. Lindberg commended the MSL team for their quick response in developing the operations protocol. Prof. Joanne Gabrynowicz asked whether the use of the NPR 8020.12 was documented in each briefing. Dr. Lindberg asked if the operations protocol would be used for future missions; e.g., M2020. Dr. Meyer stated that the odds are likely, but it is not codified. Dr. Conley noted that the protocol is codified in the categorization letter. Dr. Meyer noted, in response to another question, that no special regions have been identified in Opportunity's traverse path.

Discussion with Acting SMD AA

Mr. Geoff Yoder, acting SMD AA, gave an overview of the current status of SMD, and the path forward. The search is on for the next AA, but Mr. Yoder expressed the intent to continuously improve day-to-day processes, and had initiated an SMD Directorate Program Management Council that includes both the Agency's Chief Technologist and Chief Scientist, to ensure SMD is looking at all the fundamental disciplines. SMD is also drafting NASA Interim Directive (NID) 8020.12 to clarify any short-term confusing issues on PP and is on the way to a final edition. PP enables NASA to strike the right balance between exploration and discovery in the context of PP, and is thus very important to NASA. As new PP technologies arise, NASA must be able to adapt them to protect the Earth, as well as the scientific integrity of a returned sample. Mr. Yoder asked to be briefed on a quarterly basis on PP, and noted that some actions were under way via the Agency Program Management Council to forge a better connection with PP. These actions included a risk assessment of the PP Implementation Plan. Mr. Yoder assured PPS that full Agency attention was being given to the M2020 Planetary Protection Plan.

Dr. Lindberg thanked Mr. Yoder for the update, noting that when PPS had first heard the technical approach to M2020, it was clear that it was a work in progress. PPS had been concerned about levels of cleanliness re: sample containment and contamination. Mr. Yoder agreed that the Planetary Protection Implementation Plan must contain detailed and probabilistically bounded descriptions of how each stage of sample return must be carried out to meet the goals of both scientific integrity and PP. Dr. Doran asked for Mr. Yoder's view of a future MSR mission. Mr. Yoder replied that a specific return mission is not on the books today, so that the effort has been concentrated on making the samples collectable. There are multiple ways to bring them back, via human exploration, partnerships with other agencies, or private industry. The whole Journey to Mars concept is viewed as open to discussion. Requirements, before launching M2020, will be focused on cataloguing possible contamination sources, and studying the implications for handling blanks on Earth, which were heretofore not as explicit as possible. The Agency Chief Scientist, PSD, PPO, and other relevant offices will examine the final version of NPR 8020.12 before it goes to signature. Mr. Yoder stressed that the editing process is looking to clarify, but not change, requirements.

<u>Public comment period</u>

Dr. John Rummel, SETI Institute, offered several comments in response to the day's briefings:

- It was not clear to Dr. Rummel how SpaceX, NASA, and FAA will work together to ensure that common planetary protection standards are implemented, and whether it is NASA's intention to uphold its own planetary protection requirements as part of NASA's cooperation with SpaceX (as provided for in NPR 8020.12)

- Dr. Rummel asked how NASA will ensure that technologies and engineering solutions in use by other industries can be applied/adapted to NASA needs. These include medical device manufacturers and the petroleum and natural gas industries, which are applying technologies that NASA could use.

- Dr. Rummel thought it would have been useful if the PPO or the MEP could have shown specific information on the status of M2020 planetary protection requirements and plans, including their post-PDR PMC approvals, to set the stage for Geoff Yoder.

- Of the "Desired Orbiter Capabilities" shown by Dr. Meyer, Dr. Rummel believed none of them benefit from the orbiter being able to return to Earth.

- Dr. Rummel believed Dr. Vasavada gave an excellent presentation, about a good step forward for Mars rovers in sensitive areas.

- Dr. Rummel appreciated that there is an interim directive being hatched to clarify NPR8020.12 prior to it being updated in the next year. He also expressed hope that the revised/updated planetary protection plan for Mars 2020 will cover ALL of the steps that M2020 is taking to meet planetary protection requirements.

- Dr. Rummel asked how a Mars project could accommodate a "tech demo" helicopter that was not selected for science reasons and has ~14kg of mass, when the same project says that they cannot afford to implement a cover on their sample acquisition hardware, which is something that is a planetary protection requirement.

- Dr. Rummel asked why the international agency representatives to the PPS were not present and why there were few PPS members present.

Discussion

Dr. Imperiale raised concern about an apparent lack of communication at NASA, especially given that the operations protocol had not vetted by the PPO before it was adopted for MSL operations. The subcommittee discussed aspects of the briefing that might need further attention. Dr. Meyer commented that he had thought he had sent a draft of the operations protocol to Dr. Conley, and that the miscommunication could be due to this oversight. Dr. Kaminski clarified some issues about international affiliates, in that they don't contribute to the voting on the PPS. Dr. Conley noted that international members serve as liaisons from their respective agencies. There was some lingering disagreement over the interpretation of the NAC charter with respect to international members. It was discussed that PPS should request representation from the UAE, Japan, and India.

Dr. Lindberg recused himself from the following commercial space industry discussion due to potential conflicts, and left the meeting room while Dr. Doran acted as temporary chair.

Prof. Gabrynowicz agreed with Dr. Rummel about the urgency of considering PP with respect to nongovernmental launches. She noted that the Office of Science and Technology Policy (OSTP)

recently issued a report to Congress recommending a new interagency process, to include NASA, for these missions. Elon Musk plans to send the Red Dragon capsule to Mars by 2018, and has also considered plans for sample return and human colonization. Prof. Gabrynowicz further reported that in 2014, there was an attempt to pass a law that would have codified asteroid mining, which failed. Another bill later passed that contained a recommendation for something other than licensing for the space industry. OSTP issued a report on April 4, 2016 recommending to Congress that they come up with an interagency mission authorization process that includes FAA and NASA, which would be similar to the process that the Department of Transportation (DoT) uses for payloads. DoD and the intelligence community also have an interest in this process. The final process is still to be decided. One of the issues is who will do what in this process. The Outer Space Treaty holds that all parties to the treaty must authorize and continually supervise the commercial entities. In the U.S., this is usually done through licensing. The Department of State says this mission authorization process, in the US, must also pay close attention to the terms of the Outer Space Treaty. In the past, PPS has recommended that the US be part of the approval of launch processes and may want re-issue this recommendation. Prof. Gabrynowicz's opinion was that while commercial entities don't want government interference, licensing is nonetheless legally valuable to, and hence an attractive option for, these companies. A license is clearly defined, but a mission authorization is undefined at present. Proponents believe they can influence the political process to have it go the way want it to go. Dr. Conley noted that she had been having informal communications with SpaceX for many years, and suggested the PPS might recommend that NASA formalize the relationship. Prof. Gabrynowicz believed PPS could make a strong recommendation based on existing NASA policy and US laws, as US treaty obligation is at play and no one knows how to deal with it just yet.

June 2, 2016 (Day 2)

Introduction

Dr. Kaminski opened the meeting and reviewed the day's agenda. Dr. Lindberg made some opening remarks with attention to a prior recommendation to fortify the staffing in the Office of PP, and for a new recommendation on COSPAR efforts in PP technology. He also recommended a revisit of the discussion on commercial space mission authorization to take place once again, with Dr. Doran acting as temporary chair. Dr. Conley clarified some prior comments on COSPAR and US civil servants' ability to travel, Department of State warnings on Turkey, and environmental impact statement regulations.

NASA Life Sciences Capability Leadership

Dr. Craig Kundrot spoke about a "new fulcrum" for concerns about capabilities in PP. NASA's aspirations always exceed its budget, and aspirations change faster than it can complete missions. Another challenge is coordinating across the 150 programs and 10 field centers. These challenges have led to the idea of creating a Capability Leadership, a set of advisers to the Agency's top managers and management councils, to ensure proper alignment across mission directorates and field centers, guide prioritization of tasks, strategic hiring, identify

opportunities for investment in life science research, and solicit innovative ideas from outside the Agency. Leadership areas are in Engineering, Research (Earth Science and Life Science), and Services. Dr. Kundrot sits within the Office of the Chief Scientist and is serving as the leader of the Life Sciences Research Capability Team (LSRCT), its purview spanning Human Research, Space Biology, PP and Astrobiology. LSRCT goals are to promote awareness of and coordinate Life Science capabilities and needs within NASA, and to provide recommendations to senior management through Agency Program Management Council, Mission Support Control, and other conduits. The team is trying to think decades out, particularly when assessing workforce needs (30 years hence), in the same timeframe as envisioned for potential human presence on Mars. The team is using a purpose-driven framework. For PP, there is a one-sentence purpose, from which goals are derived, as well as 20 research questions. Given the questions, the goal is to address the capabilities needed to answer those questions. Centers are brought into the framework from the programmatic flowdown. NASA is addressing Tier 1 questions such as: does NASA have the proper Life Science Research capability to efficiently execute present and future missions? If not, what corrective measures are needed? Tier 2 questions address current capabilities, shortfalls, duplicative efforts, and what collaborations would be helpful, inside and outside the Agency. The effort will draw on NASA civil servants, contractors, grantees, international partners, academia, and commercial concerns, to develop a taxonomy of disciplines, to determine whether a NASA civil servant needs a particular skill set or knowledge, or whether NASA just needs to know who to call. In either case, the right skill set will be needed to write the right call, to identify a problem and translate it properly to let the experts figure out how to solve the problem.

There are important areas in the life sciences workforce that will need succession planning. Radiation biology, for example, needs to train and maintain junior and senior level civil servants. In broader areas such as visual impairment/intracranial pressure, NASA can plan to utilize people brought in through Intergovernmental Personnel Act agreements ("IPAs"), contractors, and grantees rather than hire civil servants. Systems biology is another field that is moving too fast for NASA to commit to specific expertise; therefore it would be likely that NASA will use IPAs, contractors, and grantees for this area as well.

NASA is just about one year into the effort of assessing the match between needs and capabilities. Beginning in the Fall, the team will begin to coordinate with outside organizations. Dr. Kundrot noted that this would be an important time to call attention to PP research needs, with heightened access to senior management. He recommended that the PP community take advantage of the unusual level of life research visibility to the NASA AAs, representatives from field centers, OCT, OCS and the Associate Administrator Robert Lightfoot. The team also provides a venue for developing cooperation between HEOMD and SMD. In context of HEO's Journey to Mars vision, heightened attention to life science research through this effort will help bring awareness to the "flow of life" that HEO must consider.

Dr. Lindberg asked how the PPO responsibility is aligned with life science research. Dr. Kundrot described the PPO as a member of the group, shaped by NPRs and NPDs and without detailed direction from the outside. Dr. Conley added that there are representatives from the JPL PP office and Goddard Space Flight Center's contamination control office, predominantly from the implementation side. The focus of PP is to identify needs on the mission implementation side. From a standpoint of PPO responsibilities, the life sciences research activities are less relevant. PPO has a funding stream of about $500K for PP research, and therefore is usually engaged in efforts to leverage the Astrobiology budget lines, life science research line, etc. Dr. Lindberg noted that PPS has been concerned about the PPO's operational capacity to support active and developing missions, and has separate concerns about pace of NASA investment in new and improved technologies and processes to ensure adequate PP on these missions; in the areas of life detection and sending humans to Mars especially. Dr. Kundrot commented that human research and PP are applications-driven, while SMD Astrobiology and HEO space biology are basic research; life science research covers the whole spectrum, but doesn't include operations specifically. It does, however, bring operations into thinking about all of the above. Dr. Lindberg asked if the LSRCT could advocate for more funding, and if it was analyzing PP staffing in the context of workforce needs. Dr. Kundrot replied that the PP workforce needs would be considered, and results could be brought forward to the SMD AA as well; the team is just looking at the same problem from a more comprehensive perspective. The team doesn't have a blank check, but Dr. Kundrot noted that AA Lightfoot wants to hear about the programs that need more capability but currently do not possess it.

Dr. Imperiale asked Dr. Kundrot to distinguish between human biology and life science research. Dr. Kundrot felt life sciences in the context of NASA research was centered on biology in terms of human operations, analogous to considering human factors when designing a fighter jet, and was not based on any artificial distinctions between human and life sciences research. Dr. Lindberg commented that 90% of HEOMD's responsibility was in building rockets and spacecraft, but its responsibilities provided a good example of the need for coordination. Dr. Kundrot agreed with Dr. Lindberg's assessment that PP advocates all the way up the chain, as does the SMD AA, as does the LSRCT. He added that the LSRCT could also address the issue of where the PPO should be housed, in terms of impact on programs.

STMD Programs and Plans

Dr. Prasun Desai gave an overview of the Space Technology Mission Directorate (STMD), which is currently undergoing a senior management reshuffle as well as formulating a response to an independent review. STMD seeks to enable a new class of NASA missions beyond low-Earth orbit (LEO), deliver innovative solutions to dramatically improve technological capabilities for NASA and the US, and to reduce cost and risk of same. The effort is broader than just NASA, as STMD also seeks to create markets and spur innovation in the national arena, industry, other government agencies, and academia, through engaging the brightest minds. Guiding principles for space technology programs include: a stakeholder-based investment strategy; reliance on guidance from National Research Council (NRC) reports, NASA strategic plans, and the Hill;

investment in a comprehensive portfolio; focusing on high-risk, high-payoff, transformative technologies; development of partnerships to leverage resources; selection of projects via merit-based competition; execution with lean structure projects that are either infused rapidly or terminated promptly, all with the goal of placing NASA at technology's forefront and refreshing the Agency's workforce.

STMD is comprised of 9 programs in three basic areas: transformative cross-cutting technology (technology demonstrations, small spacecraft); pioneering concepts/developing innovation community (NASA Innovative Advanced Concepts (NIAC), space technology research grants, center innovation fund); and creating markets and growing an innovative economy (Centennial Challenges, flight opportunities, Small Business Innovation Research [SBIR] and Small Business Technology Transfer [STTR] programs). Dr. Goeres asked about ownership of IP in these cases. Dr. Desai explained that NASA goes through the standard legal issues case by case, which usually result in acquiring usage rights by the government. Dr. Desai cited a recent "postage stamp" spacecraft concept, in which small, lightweight craft are propelled by light beams; that concept had been rooted in a NIAC study on the beaming concept. Other projects are in the areas of asteroid mining and new propulsion technologies. All of these programs are for developing capability, and any of them can be used for PP. STMD concepts are inserted into particular programs based on technology readiness level (TRL).

The STMD budget is $686M per year. Asked how many PP technology investments had been made in STMD, Dr. Desai noted there had been none. He added that the budget is not discretionary and often includes set-asides, the latest (FY16) with a $140M price tag. Dr. Lindberg asked how STMD coordinated with PP on building PP into technologies for exploration beyond LEO. Dr. Desai said he had instructed in particular the game-changing facet of the STMD program to factor those aspects into development, such as in investments in Stirling engine materials. PP is not part of the selection process, but it is factored into the engineering process once a proposal is selected. The project is then evaluated during the monthly and quarterly reviews and Level II program offices. Dr. Conley commented that she had received no requests from STMD on PP. Dr. Desai noted that STMD's MOXIE (an ISRU experiment) is part of the M2020 project, and that the PPO is certainly aware of it.

Dr. Lindberg asked how PPS could get some attention paid to developing cleaner systems from a biological standpoint, which is a critical need if HEO wants to put humans on Mars. PP has become critical for the Agency in terms of the Journey to Mars. Dr. Desai identified the strategic investment planning process as the avenue in which PP could be addressed; the relevant strategic theme would be "Get There, Land There, Live There." Dr. Lindberg was concerned that PP technology was not getting into the roadmaps. Dr. Desai also cited PP guidance from the NAC and from the NRC. In addition if HEO and SMD have a driving need, STMD converses with them on a daily basis; that may be another way to elevate awareness of PP. Dr. Mike Seablom represents PP at the program management councils. Depending on the technology, the division directors come to the Agency Program Management Council. Whether PP is mentioned depends

on the technology: if a material or spacecraft is not going to be on another body in the solar system, it is not in the conversation. Dr. Desai noted that any PP requirements for a mission must come through the directorate that is supporting the mission. If STMD knows the need for a specific requirement, it can find a home for it. Dr. Desai's slides provided more information on which subcategories PP might fit into the STMD portfolio.

Dr. Desai briefly the reviewed budget chart, saying that STMD was originally envisioned at $1B per year, but it has never been beyond $500-600M. The directorate has had to continually descope to accommodate set-asides. The Congressionally mandated SBIR program, e.g., is a third of the budget. Dr. Desai suggested that PP needs be addressed through directorate requests, system maturation teams, and the game-changing development budget lines.

Antimicrobial surface technology

Dr. Goeres gave an overview of the state of the art of antimicrobial surface science, and how current technologies might be useful to NASA. The briefing centered on biofilms, which generally exist in aqueous environments but also form on dry surfaces. Biofilms have unique and complex lifecycles. Once microbes attach and form a biofilm they are exceptionally difficult to eradicate, thus preventing attachment has become a "holy grail" in the field. The goal of current preventive technologies is to mimic, coat, engineer or discover an intrinsically bioactive material that does not allow microorganisms to attach. To illustrate the difference between preventive versus eradicative measures, takes 1-3 mg/L of chlorine to control bacteria in a swimming pool. By contrast, it takes 5000mg/L chlorine needed to eradicate biofilm organisms. Biofilms also form a slimy matrix, or extracellular polymeric substance (EPS), that is characteristic of plaque on teeth, or alga on rocks. Preventive materials are used throughout the industry today: there are now shower curtains made of antimicrobial materials to retard mold formation, and tennis shoes made with biofilm resistant textiles. Medical devices commonly employ these materials to prevent infection, as for indwelling catheters.

Classes of antimicrobial surfaces are based on mechanism of action (MOA): repelling surfaces that do not allow for protein adhesion or that eliminate binding sites (sharklet technology biomimicry; slippery liquid-infused porous surfaces [SLIPS] technology), or self-cleaning or sloughing surfaces; killing surfaces (contact-active or release of biocidal substances such as silver or antibiotics); and combination surfaces (release of biocide and renewal of surface, e.g.). Test methods are also based on MOA as well as applications. Parameters to consider include controls, microorganisms, conditioning fluid (how will it change the antimicrobial surface properties? will the surface lead to resistance development?) toxicology (is it toxic to the ecosystem?), method sensitivity (can it detect an extremely low level of microorganisms?), method bias (technique used to recover microorganisms from the surface), rate (how fast does the active surface work?), and duration. All surfaces will eventually fail; it is important to know when and how they fail.

There are many standardized test methods for evaluating microbes on surfaces. Dr. Goeres provided a reference for these methods [Askew, Peter. Efficacy Assessment of Treated Articles: A Guidance. dx.doi.org/10]. There are several methods contained in the guide that may be useful to NASA PP concerns. There are many copper alloys registered with human health claims and the Environmental Protection Agency (EPA) which have successfully demonstrated reduction of microbial viability. Copper is intrinsically toxic to bacteria. Silver is also biocidal and works best when silver ions can leach into liquid or colloidal preparations. While leaching technology would not seem to be appropriate for spacecraft, Dr. Conley mentioned that a liquid method might be relevant for temporarily coating the exterior of a fairing.

Dr. Goeres stressed that killing and removing biofilms are two different issues; one must understand how chemistry will affect a surface—is it killing and not removing organisms, or removing and not killing? In terms of potential spacecraft materials, copper would do better than aluminum at preventing biofilm formation, by hypothesis. Consideration of such materials would be a good topic for inclusion in the PP Technology Team's deliberations. Dr. Pugel added that there is plenty in the literature describing biofilms on metallic and other surfaces, and sent a reference to Dr. Kaminski to share with the PPS. Dr. Imperiale asked if there were any difference in species derived from humans vs. the field. Dr. Goeres responded that the operative issue would be to identify the best organism to use as a test subject, and cautioned that biofilms are complex ecological communities that are often composed of multiple species and genera of fungi, algae, and bacteria, complicating appropriate study methods. Dr. Conley noted that PP is generally focused on organisms identified in cleanrooms. Dr. Goeres suggested a wider use of many techniques to identify organisms: microscopy, total organic carbon, autofluorescence detection, and plate counts, among others.

ESA PP/COSPAR update

Dr. Gerhard Kminek presented an update on ESA PP and COSPAR activities. ESA's Rosetta mission is classified as a Category III for one Mars flyby/gravity assist, and Category II for its target, the comet Churyumov-Gerasimenko. The final disposition of the spacecraft, which is still orbiting, has been decided. End-of-mission (EOM) is scheduled for September 2016, with landing on the comet selected as means of termination. Over the next 50 years, the trajectory of the comet crosses the Mars orbit at a closest approach of about 1 astronomical unit, presenting no risk to Mars via impact. The spacecraft Mars Express, in a highly elliptical orbit, exhibits no issues with orbital stability or risk of impact on Mars over 50 years. Its EOM scenario was a compromise between science and PP; the decision was that Mars Express will remain in the current stable orbit, which has an orbital lifetime well beyond 50 years, but its battery lifetime is likely to expire by 2020. ESA is currently discussing passivation for EOM. The active ExoMars 2016 mission, the first launch within the ExoMars program, is comprised of an orbiter and lander. The orbiter is one ton heavier than MRO. Launcher injection for cruise to Mars worked very well and required no correction maneuvers. The landing ellipse covers also the Opportunity track. The orbiter is classified as Category III, and the lander as Category IVa. ESA did a detailed PP analysis of ExoMars 2016 due to its long aerobraking period and the risk of micrometeoroid

impact. A bioburden-controlled assembly was used for the Schiaparelli lander, and dry heat sterilization for most of the flight hardware. More than 3000 assays were performed, including rapid assay techniques. A PP certificate of compliance was issued on 8 March, and ExoMars 2016 launched on 14 March 2016. The lander is scheduled to separate on 16 October, and the TGO main science phase will begin at the end of 2017. Dr. Kminek commended Thales Alenia Space Italy and ESA's Russian partners at Baikonur for their cooperation on the planetary protection aspect of the mission.

Regarding ExoMars 2020, its mission elements include a carrier module, descent module, and rover module with a Pasteur Payload. The mission has completed a systems requirements review and a preliminary design review (PDR), while landing site selection is ongoing. ExoMars 2020 is seeking life and is therefore a Category IVb mission. Bioburden control, with credit given for break-up/burn-up for the cruise stage, is being used to implement the planetary protection requirements. ESA is using a new aseptic contamination controlled glove box assembly line (for part of the drill assembly, and for elements of sample handling and analysis for life detection) at the Thales site in Turin. The mission will also be using a new class-10,000, bioburden-controlled cleanroom for rover assembly at the Airbus site in Stevenage. Qualification models are being used to test procedures. The mission will use a combination of cleaning and dry heat before entry of the life detection componentry into the glove-box. Other processes to be used are CO_2 snow cleaning, purging with warm argon gas, and sealing with a gaseous overpressure before the components are delivered to the rover.

Dr. Kminek commented that the final bioburden numbers for the latest launch had been on average about 30 spores/square meter measured, and a conservative recontamination analysis indicated about 70 spores/square meter. The total bioburden was in the range of 300,000 (as opposed to the requirement of 500,000), half surface, half encapsulated. Phobos sample return is still being assessed. Different models have predicted transfer of large amounts of material as young as 3 million years. The hypervelocity impacts of material on Phobos and the high radiation environment are thought to be sufficient to sterilize sample material. Hypervelocity tests carried out at the Fraunhofer Institute (5 km/sec into low-density materials), and a subsequent workshop, have established a baseline for the types of tests required to support an assessment of the sterilization potential of Martian material transferred to Phobos. Work is ongoing at the consortium at Open University, NASA Marshall Space Flight Center and Purdue University. Results will feed into assessment of PP category and there should be a report out by the end of this summer.

Dr. Kminek addressed Mars Sample Return, which presents a new scenario for cooperation. ESA and NASA have had recent bilateral discussions, but there is no commitment on either side as yet. The big picture view includes sample acquisition by 2020, and there could be an ESA contribution in 2022 to capture the sample, or a courier mission with an Earth Return Vehicle. Elements of MSR will be based on the 2008 iMars activity. ESA has initiated a contract change notice to explore accelerated developments for their sample capture and sample containment

technologies in support for Mars Sample Return and is also preparing a proposal along these lines for the next ministerial council, including a potential a courier mission to return sample to the Earth. It is estimated that about 12 years would be needed to develop a sample receiving facility containment technology. Asked if ESA might develop a Mars Ascent Vehicle (MAV), Dr. Kminek said clearly no. This was always considered to be part of a NASA interest and contribution.

Other activities include the European Commission funding of EuroCARES (European Curation of Astromaterials Returned to Earth from Space), a three-year academic/industrial effort on developing a European sample curation facility, and a PP effort focused on exploration of the outer solar system. The multinational project includes ESA's participants, Russia, China and Japan, and an observer from the US National Academies.

Based on the most recent COSPAR meeting in 2014 Dr. Rummel arranged a special section in *Advances in Space Research*, including 5 papers on PROCYON, and the effects of hydrazine vapor on Bacillus spores. The Planetary Protection Forum discussion was published December 2015 in *Space Research Today*, and identifies three areas that would benefit from further discussion. The Planetary Protection Colloquium resulted in some recommendations for Europa and Enceladus, and updates on Mars Special Regions requirements. In the case that PPS wishes to voice an opinion on recommendations, Dr. Kminek asked for communications before 15 July 2016, or that PPS voice an opinion in the minutes. Dr. Lindberg noted that he had already transmitted the recommendations to the PPO, which were accepted by PPO and in progress. Dr. Conley forwarded the December 2015 minutes to Dr. Kminek to reflect formal acknowledgement.

The upcoming COSPAR Scientific Assembly in August 2016 will discuss PP workshop topics for the time until the next COSPAR assembly in 2018: two issues are proposed – planetary protection requirements for one-way and return missions to Phobos, Deimos and asteroids; and planetary protection protocols for restricted Earth return missions. In case the PPS would like to voice their opinion about the proposed topics or identify other topics, Dr. Kminek asked to please reflect this in the meeting minutes or write a letter by 15 July 2016.

Spacecraft Microbiology in Human Exploration Missions

Dr. Mark Ott presented a briefing from Johnson Space Center. The center has carried out an enormous amount of work on human-rated spacecraft, a very nonsterile interior. Adverse effects from microorganisms such as infectious disease (skin infections), biodegradation, systems failure, food spoilage, and release of volatiles are common issues encountered on the International Space Station (ISS). Prevention is accomplished through primary microbial control in vehicle design, including the use of HEPA air filters and contamination-resistant surfaces (JSC is switching to silver from iodine for the Orion crew vehicle). Control also consists of operational activities, i.e. the health stabilization program, to reduce viral and bacterial infections. Preflight

microbiological monitoring of crew, food, potable water, cargo, etc., is part of the ongoing program. Microbiological requirements include numeric standards for air, surfaces and water. These numbers are low from a human perspective, but high from a PP perspective. In preflight monitoring, one finds occasional opportunistic pathogens such as *Pseudomonas aeruginosa, Staphylococcus aureus*, and *Burkholderia spp*. There is always presumed to be a contamination potential in human missions issuing from preflight contamination, the complexity of spacecraft environments, and astronaut activities such as eating and hygiene.

Monitoring during spaceflight includes the use of media-based techniques for testing water (coliform bacteria, and others), surfaces and air. ISS air and surface monitoring over the first 10 years has resulted in cultures that mimic exactly what one would find in a home or office. In water, no medically significant organisms have been isolated, other than common isolates such as *Sphingomonas* and *Burkholderia*. Filters are not analyzed for organics, and it is thought that any bacteria that develop are actually growing downstream of the filters. Over the past 15 years, microorganisms isolated from ISS remain common terrestrial organisms. NASA is establishing a "microbial observatory program" on the ISS in response to advice from the NRC.

Multiple experiments over the past 50 years indicate that there are some unique microbial responses that appear in spaceflight culture. In *Salmonella typhimurium* experiments, space vs. terrestrial, virulence is found to vary 2.7-fold, with the bacteria exhibiting more virulence in space. A second experiment showed a 6-fold difference. Addition of inorganic ions to cultures negated this effect. Differing regulation of bacterial genes is also seen during spaceflight: the global gene regulator Hfq is associated with some of the downregulated genes. EPS also formed in higher levels in space. *Pseudomonas aeruginosa* experiments demonstrated changes in biofilm morphology to a more "column and canopy"-like shape. There is more impact of skin-associated flora at ISS than in cleanrooms. NASA continues to track genomic changes in onboard microorganisms, and is working with a national laboratory on pathogenics, as well as with the Russian Joint Research group on sampling techniques and monitoring. NASA is also working to use historical microbial isolates in grant solicitations and to make the archive more widely available.

Other studies pertinent to environment include monitoring of astronaut microbiomes via sampling of skin sites, nostrils, feces, blood, and saliva. The Veggie spaceflight experiment (growing vegetables on ISS for consumption) and Microbial Mutation Rate (currently not known) are two ongoing studies; the latter will use whole genome sequencing to determine mutation rates. In order to prevent contamination of the lettuce, ISS is doing more environmental sampling around the Veggie apparatus itself, as well as actively disinfecting with citric acid, and other agents. This is a relatively new area for NASA. New monitoring technology under consideration includes the Razor system, which looks at specific targets using quantitative polymerase chain reaction, and the MinION system (nanopore technology), both of which are scheduled to fly on ISS in July.

Work carried out in the 1980s showed changes in antibiotic resistance in ISS microorganisms. NASA would like to look at the pharmacokinetic and pharmacodynamics occurring in flight; this will require an onboard animal experiment, most likely. There is also transcriptomic data that show gene expression of DNA damage response, but which is intertwined potentially with other insults (such as radiation). There is also evidence of sequence changes around "hot spots," associated with both gain and loss of resistance, and other changes seen at the level of the proteome.

Overall, NASA maintains microbial environment concentrations at low levels, and is actively learning how to improve design, understand the spacecraft microbiomes, and in particular to understand it better for humans traveling in space for longer periods.

Life detection investments in SMD

Dr. Mary Voytek, Senior Scientist for Astrobiology, presented a briefing on NASA's progress in life detection technologies. An Astrobiology Science Strategy was published in the Fall, which is a NASA version of a decadal survey. The PDF version is available on the web at astrobiologyfuture.org. The strategy consists of six major research themes: identifying sources of abiotic compounds; synthesis and function of macromolecules in the origin of life; early life and its increasing complexity; co-evolution of life and the physical environment; identifying, exploring and characterizing environments for habitability and biosignatures; and constructing habitable worlds.

Within SMD the Astrobiology research program encompasses Planetary Science and Technology from Analog Research (PSTAR), Habitable Worlds, Exobiology-Evolutionary Biology, Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO, instruments through TRL 3), the NASA Astrobiology Institute, and NExSS: NASA Exoplanet System Science. Astrobiology is guided by studies from the National Academies and recommendations from the Committee on Astrobiology and Planetary Science (CAPS), science needs in support of ongoing and future missions, as well as other NASA concerns. The NASA microbiome study is a priority of OSTP. SMD has invested in research on the probable first common ancestor of life, while PPO funds genetic inventories, and a $25M Ocean Worlds program may lead to the development of technologies for assessing microbiomes in extreme environments (such as icy worlds). HEOMD is supporting a GeneLab project, a new space life sciences research project, as well as the astronaut twin study (Mark and Scott Kelly).

SMD is now soliciting COLDTech, Concepts for Ocean Worlds Life Detection, which supports the development of spacecraft instruments for both surface and subsurface exploration of Titan, Europa, and Enceladus. The goal of the program is to develop and reduce the technical risk of instruments and technology for future missions.

Defining life in Astrobiology *per se* is based on the concept of life as a self-sustaining chemical system capable of Darwinian evolution (chemistry with history and memory). The general theory of living systems holds that life uses water as a solvent, is built from cells, is based on a two-biopolymer system; and is thermodynamically dissipative. NASA has created a "life detection" ladder (hosted on the astrobiology website) that catalogues the various parameters associated with life, with characteristics such as metabolism, growth, and reproduction at the top end and habitability at the bottom end. Suspicious biomaterials (not necessarily biogenic) are in between. The ladder helps to conceptualize factors needed to determine false positives or false negatives.

NASA is supporting life detection workshops, such as Agnostic Biosignatures in late summer of this year; Extant Life on Ocean Worlds Workshop in early fall 2016 at Goddard Space Flight Center; and the Workshop on Advanced Technologies for Life Detection on Icy Planets/Icy Terrain in 2017. Dr. Goeres asked about thought exercises, such as differences in basic thermodynamics or breakdowns in fundamental physics. Dr. Voytek noted that the current belief is that life likely arose a number of times, and what we see today is the successful model. Practically speaking, it is prudent to stay within the current bounds of physics to understand the biology of any extraterrestrial living system. Asked about GeneLab, Dr. Voytek described it as an infrastructure port for developing bioinformatics to inform future investments. HEO is also working with the Sloane Foundation to develop collaborations with joint funding. Dr. Lindberg commented that NASA was once the largest single funder of research into the origins of life. Dr. Voytek noted that in the US, the NASA Astrobiology program overlaps somewhat with the National Institutes of Health (NIH) and the National Science Foundation (NSF). NASA may connect with NIH over the cancer question in the future, and is already working closely with NSF and their Chemistry of Life division. NASA also co-funds the Center for Chemical Evolution at Georgia Institute of Technology, along with NSF. The Ideas Lab in the UK has put together a scientist with a facilitator to produce proposals on questions of life within the two-polymer (DNA/RNA) architecture. ESA also has some investments, as does Japan (prebiotic chemistry). NASA is working with about 16 countries in various ways. Dr. Voytek summarized by commenting that while Astrobiology doesn't tend to fund PP, it's extremely important that "we don't detect ourselves" while endeavoring to find life in the universe.

Public comment period

Dr. Rummel reiterated his concern that there has been no discussion as to how repeated requests concerning PP have never made it into STMD plans. He stated that advanced technologies can solve problems for Europa, Enceladus, and special regions on Mars. He encouraged the PPS to keep pushing on this effort and issue.

Discussion of findings and recommendations

PPS discussed findings and recommendations, including a recommendation that

NASA assign an additional civil servant to the Office of Planetary Protection, given the accelerated rate at which PP-oriented tasks are being required for both NASA and non-NASA space exploration.

PPS considered an observation noting that NASA should take heed of the ESA PP community's PP investments in the outer solar system as an opportunity for NASA to coordinate with ESA efforts in analogous PP investments.

PPS considered a recommendation that the PPO work with the SMD AA and HEOMD PP group to articulate to STMD the critical need for investment in PP technology for future robotic and human planetary missions. Dr. Doran said PPS should merely state that STMD should invest in PP technology as necessary. It was noted that this same request was made previously, as reflected in the minutes of the May 2012 meeting of PPS.

Dr. Goeres commented to PPS as a whole, after hearing Dr. Kminek's details on how PP is carried out at ESA, that he had made it very clear how decontamination and sterilization is carried out at ESA. She did not see this clarity in the NASA mission briefings, and felt that more clarity in how NASA missions are achieving their PP criteria would benefit PPS, in that it would enable the subcommittee to evaluate their methods more adequately. Dr. Doran felt that PPS could specifically request more detailed overviews when they were felt to be necessary. Dr. Lindberg shared Dr. Goeres' view and asked that the observation be captured in the minutes.

Dr. Lindberg stepped out briefly, and Dr. Doran took over as chair, as PPS re-addressed commercial space efforts in the context of PP and mission authorizations for commercial space flight. The PPS considered a recommendation that NASA PP be part of the newly defined mission authorization process, based on previous language used by PPS. Prof. Gabrynowicz offered a draft recommendation that PPS addressed, while Dr. Rummel commented that at the heart of the draft recommendation would be that NASA include COSPAR principles, in conjunction with FAA authorities, as part of its evaluative process. Dr. Imperiale commented that the recommendation should simply state that commercial entities should play by the same rules as governmental entities.

Dr. Lindberg returned to the room, and reiterated the intent to use the group's draft recommendation to begin to ask the question on the mission authorization process. As a closing action, Dr. Lindberg recognized two members of PPS who have just rotated off service, Drs. Yulia Goreva and Penelope Boston.

Dr. Lindberg thanked everyone for a productive meeting, and adjourned at 3:21 p.m.

Appendix A
Attendees

Planetary Protection Subcommittee Members
Robert Lindberg, University of Virginia, *Chair PPS*
Colleen Cavanaugh, Harvard University*
Peter Doran, Louisiana State University
Joanne Gabrynowicz, University of Mississippi
Darla Goeres, Montana State University
Michael Imperiale, University of Michigan
T.C. Onstott, Princeton University
Nick Steneck, University of Michigan

U.S. Agency Representatives to the PPS
Stacey Zee, Federal Aviation Administration

International Space Agency Representatives to the PPS
Gerhard Kminek, European Space Agency*
Victoria Hipkin, Canadian Space Agency*

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

NASA Attendees
Gabriel Adler, NASA HQ
Gale Allen, NASA HQ
Louis Barbier, NASA HQ
Pat Beauchamp, NASA JPL
Doug Bernard, NASA/JPL
Charles Brinkman, FAA*
T. Jens Feeley, NASA JPL
James Green, NASA HQ
Doug Isbell, NASA/JPL*
Craig Kundrot, NASA HQ
Amruta Mehta, NASA/JPL
Michael Meyer, NASA HQ
Betsy Pugel, NASA HQ
Tom Norwood, NASA HQ
Mark Ott, NASA JSC*
Christy Rivera, NASA/HQ
Gregory Robinson, NASA HQ
Ruben del Rosario, NASA HQ
Mitch Schulte, NASA HQ

Marc Shepanek, NASA HQ
Bette Siegel, NASA HQ
Katie Spear, NASA HQ
George Tahu, NASA HQ
Ashwin Vasavada, NASA/JPL*
Mary Voytek, NASA HQ
Dan Woods, NASA HQ
Geoff Yoder, NASA HQ

Non-NASA Attendees
Marc Allen
Sara Barber, American Institute of Physics Congressional Science Fellow*
Alissa Haddaji, COSPAR
Irene Klotz, freelance science journalist*
Sean Pitt, SpaceX*
John Rummel, SETI Institute
David Smith, National Academies*
Marcia Smith, spacepolicyonline.com*
Ana Wilson, Ingenicomm
Alexandra Witze, freelance science journalist*
Joan Zimmermann, Ingenicomm

* Participated remotely

Appendix B
Committee Membership

Robert Lindberg (Chair), University of Virginia
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
Nicholas Steneck, University of Michigan
Meenakshi Wadhwa, Arizona State University

Catharine Conley, Planetary Protection Officer, NASA Headquarters
Amy Kaminski, Executive Secretary, NASA Headquarters

Agency Representatives:

Amber Charlesworth, U.S. Department of State
Victoria Hipkin, Canadian Space Agency
Gerhard Kminek, European Space Agency
Michel Viso, CNES/DSP/EU
Stacey Zee, Federal Aviation Administration

Subcommittee Administrative Support:

Ann Delo, NASA Headquarters

Appendix C
Presentations

1. Planetary Protection at NASA: Overview and Status; *Catharine Conley*
2. Planetary Science Division Status Report; *James Green*
3. Mars Exploration Program Update; *Michael Meyer, Ashwin Vasavada*
4. NASA Life Sciences Capability Leadership; *Craig Kundrot*
5. Space Technology Mission Directorate Overview; *Prasun Desai*
6. Antimicrobial Surface Technology: An Overview; *Darla Goeres*
7. COSPAR Update/ESA Planetary Protection Update; *Gerhard Kminek*
8. Spacecraft Microbiology of Human Exploration Missions; *Mark Ott*
9. Life Detection Investments in SMD: NASA Astrobiology Program; *Mary Voytek*

NASA Planetary Protection Subcommittee
Meeting Agenda
June 1-2, 2016
NASA Headquarters, Room 1Q39
In-person and remote access details listed at end of agenda

June 1, 2016

9:30 am	Welcome, orientation, introductions	Amy Kaminski, NASA HQ
9:45 am	Words from the PPS chair	Robert Lindberg, Univ. of Virginia
10:00 am	Planetary protection issues and updates	Cassie Conley, NASA HQ
10:45 am	Break	
11:00 am	Planetary Sciences Division update	James Green, NASA HQ
11:45am	Subcommittee discussion	
12:15 pm	Lunch	
1:15 pm	Mars Exploration Program update	Michael Meyer, NASA HQ
2:45 pm	Subcommittee discussion	
3:15 pm	Break	
3:30 pm	Discussion with SMD Associate Administrator (acting)	Geoff Yoder, NASA HQ
4:15 pm	Public comment period	
4:20 pm	Subcommittee discussion	
5:00 pm	Adjourn for the day	

June 2, 2016

8:45 am	Welcome/overview of the day	Amy Kaminski, NASA HQ Robert Lindberg, Univ. of Virginia
9:00 am	NASA Life Sciences Capability	Craig Kundrot NASA HQ
9:30 am	Space Technology Mission Directorate programs and plans	Prasun Desai NASA HQ
10:00 am	Break	
10:15 am	Antimicrobial surface technology	Darla Goeres Montana State Univ.
10:45 am	Subcommittee discussion	
11:15 am	Members pick up lunch to eat in meeting room	
11:30 am	European Space Agency (ESA) planetary protection/ Committee on Space Research (COSPAR) update	Gerhard Kminek
12:15 pm	Microbiology of spacecraft	Mark Ott NASA Johnson Space Center
1:00 pm	Life detection investments in Science Mission Directorate	Mary Voytek NASA HQ
1:45 pm	Break	
2:00 pm	Public comment period	
2:05 pm	Subcommittee discussion and findings/recommendations	
3:30 pm	Adjourn meeting	