**National Aeronautics and Space Administration**
**Washington, DC**

# NASA ADVISORY COUNCIL

## Human Exploration and Operations Committee

**August 27-28, 2018**

**Ames Research Center**
**Moffett Field, CA**

## MEETING MINUTES

**Human Exploration and Operations Committee Meeting**
**NASA Ames Research Center**
**NASA Ames Conference Center**
**Moffett Field, CA**
**August 27-28, 2018**

# MEETING MINUTES

## TABLE OF CONTENTS



***Minutes Prepared By:***
***David J. Frankel, consultant***
***P B Frankel, LLC***

**Human Exploration and Operations Committee Meeting**
**NASA Ames Research Center**
**NASA Ames Conference Center**
**Moffett Field, CA 94035**
**August 27-28, 2017**

**MEETING MINUTES**

***Monday, August 27, 2018***

Call to Order, Welcome, and Opening Remarks
Dr. Bette Siegel, Executive Secretary for the NASA Advisory Council (NAC or Council) Human Exploration and Operations (HEO) Committee, called the session of the HEO Committee to order at 10:00 a.m. and welcomed everyone to NASA Ames Research Center (Ames). Dr. Siegel announced that it was a Federal Advisory Committee Act (FACA) meeting and, therefore, will be open to the public. Minutes will be taken and posted online, along with the written presentations. Dr. Siegel explained that there will be an opportunity for the public to make comments towards the end of the meeting, and she requested that all questions and comments be held until that time.

Dr. Siegel introduced the Committee Chair, Mr. Kenneth Bowersox. Mr. Bowersox welcomed everyone to the meeting.

Human Exploration and Operations Overview
Mr. Bowersox introduced Mr. William Gerstenmaier, Associate Administrator (AA), NASA Human Exploration and Operations Mission Directorate (HEOMD), who briefed the Committee on events relating to the HEOMD.

Mr. Gerstenmaier discussed the President's three space policy directives. Space Policy Directive-1 calls on NASA to "lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities." The policy further provides that "beginning with missions beyond low-Earth orbit (LEO), the U.S. will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations." Space Policy Directive-2 is important for establishing a commercial marketplace in LEO. It provides, in part, "it is the policy of the executive branch to be prudent and responsible when spending taxpayer funds, and to recognize how government actions, including Federal regulations, affect private resources. It is therefore important that regulations adopted and enforced by the executive branch promote economic growth; minimize uncertainty for taxpayers, investors, and private industry; protect national security, public-safety, and foreign policy interests; and encourage American leadership in space commerce." Space Policy Directive-3 concerns space activities and the number of objects in orbit. It provides, in part, that "for decades, the United States has effectively reaped the benefits of operating in space to enhance our national security, civil, and commercial sectors. Our society now depends on space technologies and space-based capabilities for communications, navigation, weather forecasting, and much more. Given the significance of space activities, the United States considers the continued unfettered access to and freedom to operate in space of vital interest to advance the security, economic prosperity, and scientific knowledge of the Nation."

Mr. Gerstenmaier explained that NASA's role is to lead the exploration of space with international and private sector partners. NASA will work on reducing risks until the private sector is ready. That will allow commercial enterprise to succeed and "free-up" NASA to focus on exploration. The Exploration Campaign is a national and

Agency effort focused on three core domains: LEO, lunar orbit and surface, and Mars and other deep space objectives. The campaign has four strategic goals:

- transition U.S. human spaceflight in LEO to commercial operations,
- extend long-duration U.S. human spaceflight operations to lunar orbit,
- enable long-term robotic exploration of the Moon, and
- enable human exploration of the Moon as preparation for human missions to Mars and deeper into the solar system.

Mr. Gerstenmaier reviewed the strategic principles of human space exploration. They are: fiscal realism, commercial partnerships, scientific exploration, technology pull and push, gradual buildup of capability, architecture openness and resilience, global collaboration and leadership, and continuity of human spaceflight. He noted that humans have maintained a continuous presence for over 18 years on the International Space Station (ISS). He emphasized it is important to make sure that the transition to the next stage of LEO is seamless. He stated, "we need to make sure that we don't decide to stay on the ground and not fly."

Mr. Gerstenmaier described international interoperability standards that NASA is promulgating. The standards are modeled after radio frequency standards and ISS docking standards. Anyone who builds to those standards would be able to dock to NASA's spacecraft. One current standard is for air pressure, which eliminates the need for airlocks. New standards under development are for avionics, internal communications, environmental control and life support systems (ECLSS), power, rendezvous, external robotics, and thermal interoperability. He described NASA's open architecture, which enables NASA to accommodate multiple spacecraft. As a result, NASA is not locked into one spacecraft for cargo. Dr. Pat Condon asked how NASA deals with different safety standards when considering different operability standards and accommodating international standards. Mr. Gerstenmaier responded, "it is tough," and that NASA may look at replacing redundancy with a fail-safe philosophy. The better approach to the Moon, he noted, may be to move to a reliability standard, rather than backups. Ultimately, crews will be put at risk. The Commercial Crew Program (CCP), for example, will not meet the desired loss of crew (LOC) numbers. It is important to understand everyone's safety standards. There are going to be differences and it is important to look for the common denominators.

Mr. Gerstenmaier presented a chart showing how NASA's leadership in developing crewed missions to Mars would be sustained through building mutually-enabling exploration capabilities on the ISS, in LEO, in lunar orbit on Gateway, and through human and robotic operations on the lunar surface. He described the difficulties involved in designing for deep space human missions. Weight or mass is the most significant driver in spacecraft design. Human spaceflight risks are presented by physiological changes, space radiation, the distance from Earth, the hostile environment, and isolation and confinement. It is important to go to the Moon first to understand those risks before leaving the Earth-Moon environment. He reviewed a slide showing the relative difficulties in returning to Earth from LEO, the Moon, and from Mars. A LEO return would take three hours, reach 1,650° centigrade (C), travel at 28,160 kilometers per hour (km/h), and cover 400 kilometers (km). A lunar return would take three days, reach 2,870°C, travel at 39,750 km/h, and cover 386,240 km. A Mars return would take nine months, reach 3,425°C, travel at 43,130 km/h, and cover 62,764,420 km. Mr. Gerstenmaier noted that NASA may use gravity from the Earth and Moon to slow down a mission returning from Mars. Heatshields for a Mars return have not yet been developed.

Mr. Gerstenmaier discussed the CCP progress being made on the Boeing Starliner and SpaceX Dragon spacecraft. Crews for those missions were recently announced. To accommodate program delays, NASA will extend the stay of a Soyuz flight and may convert the Boeing test flight to an operational flight. He described the status of NASA's Deep Space Exploration System, which includes the Space Launch System (SLS), the Orion spacecraft, and modernized ground support facilities at NASA's Kennedy Space Center (KSC). He noted that for the first time at KSC, there are three pads with crew access arms.

Mr. Gerstenmaier discussed the Gateway, which will be a spaceport for human and robotic exploration to the Moon and beyond. It will enable scientific research, technology development, and commercial and international partnerships on and near the Moon to prepare for human exploration father into the solar system. Gateway will not be human rated and will only be occupied on a part-time basis. It will have a Power and Propulsion Element (PPE), a habitation module, an airlock, and a logistics module. Mr. Gerstenmaier concluded his presentation with a "swoosh" graphic showing the path to the lunar surface, with human landers on the Moon in 2025 to 2026.

Mr. Bowersox thanked Mr. Gerstenmaier for his presentation.

International Space Station Update, Accomplishments and Future

Mr. Bowersox introduced Mr. Sam Scimemi, Director, ISS, HEOMD, who briefed the Committee on the status of the ISS. Mr. Scimemi reviewed the ISS's Increment 56 Flight Plan, described its crew members, and presented a summary chart showing work performed during Increments 55 and 56. The Agency has a priority goal to use the ISS as a testbed to demonstrate critical systems necessary for long-duration deep space missions. Between October 1, 2017, and September 30, 2019, NASA will initiate at least eight in-space technology demonstrations critical to enable human exploration and deep space. Mr. Scimemi described the demonstrations that have been completed and those that are planned. The demonstrations are funded by ISS, Advanced Exploration Systems (AES), the Human Research Program (HRP), Orion, and the Space Technology Mission Directorate (STMD).

Mr. Scimemi gave an in-depth description for two research projects conducted on the ISS. The investigation Endothelial Cells in Microgravity as a Model System for Evaluation of Cancer Therapy Toxicity (Angiex Cancer Therapy) aims to culture endothelial cells in a space environment to improve testing methods for cancer treatment on Earth. The study may facilitate a cost-effective method that does not require animal testing and may help develop safer, more effective vascular-targeted drugs. The Refabricator is a mini-fridge-sized experimental payload that combines a plastics-recycling system with a three-dimensional (3D) printer. NASA will use this payload to demonstrate a capability for astronauts to recycle plastic waste and use the material to create new parts and tools to support long-duration human missions to the Moon, Mars, and deep space. Re-fabricator hardware development heavily leveraged the Small Business Innovative Research (SBIR) program.

Mr. Scimemi presented a chart showing the HRP path to risk reduction. The highest risks are space radiation exposure, cognitive or behavioral conditions, inadequate food and nutrition, team performance decrements, neuro-ocular syndrome, renal stone formation, human-system interaction design, long-term storage for medications, and in-flight medical conditions. He discussed future ISS HRP work and explained that the extreme remoteness of Mars missions with no medevac and significant communication delays drives the need for almost complete autonomy in all aspects of medical care. Providing food for a Mars mission is challenging because crew members over three years would require approximately 23,000 pounds of food with no resupply and limited refrigeration.

Mr. Scimemi presented a chart summarizing crew time utilization on Increments 55 and 56. He noted that the crews have averaged more than the required 35 hours on research. They can do that because much experience has been gained over the years spent on the ISS. During Increments 55 and 56, 261 investigations were conducted. Over the ISS lifetime, 2606 investigations have been conducted by over 3000 investigators from 103 countries, resulting in more than 1500 scientific publications. In response to a question from Mr. Lon Levin, Mr. Scimemi explained that 68 patent applications have been filed due to research on the ISS. Mr. Scimemi presented a graphic showing the countries that have been involved in ISS utilization, and he reviewed the Research Investigation List for Increments 55 and 56.

Mr. Scimemi discussed the ISS National Laboratory and described its portfolio. The key focus areas are sustainability, tissue engineering, crystal growth, advanced materials, and rodent research. The National Laboratory houses 14 commercially operated facilities managed by eight companies. He described the ISS Cotton Sustainability Challenge sponsored by Target Corporation. The challenge invited leading researchers in life sciences, physical sciences, and remote sensing to propose new experiments on the ISS to reduce the water needed for growing cotton. Mr. Scimemi described Fiscal Year (FY) 2018 ISS National Laboratory customer successes. He presented a calendar showing upcoming events for the National Laboratory and described targeted conferences, speaking opportunities, and new user engagements where the National Laboratory is reaching out to new users and promoting the ISS.

Mr. Scimemi discussed the ISS operational status and presented a chart showing crew time by sponsor for Increments 55 and 56. He described two recently completed U.S. extra vehicular activities (EVAs) and two upcoming U.S. EVAs. He presented a chart showing the status of consumables and noted that the limiting consumable is food. NASA strives to maintain onboard a six-month food supply, and there has been a regular cadence in cargo vehicles.

Mr. Scimemi described the Orbital ATK (OA)-9 and the SpaceX-15 mission successes. He reviewed the mission status for HII Transfer Vehicle (HTV)-7 and Northrop Grumman Commercial Resupply Service (CRS)-10. He noted that HTV is unique in its ability to carry racks in the Pressurized Logistics Carrier. Mr. Scimemi discussed the status of CRS-2. Those missions are expected to begin in 2019 and will be flown by Northrop Grumman, SpaceX, and Sierra Nevada.

Mr. Scimemi discussed the ISS transition. NASA has released a NASA Research Announcement (NRA) to solicit proposals for study activities on developing a LEO commercial market where NASA could be one of many customers. Twelve study selections were awarded, and final study reports are to be delivered to NASA in December 2018. He described NASA's long-term needs for a LEO platform. Exploration-enabling technology demonstrations will require a LEO platform beyond 2024. The ECLSS for exploration requires continued testing on a permanently-crewed platform to validate reliability for long-duration missions and allow infusion of new technologies. Potential analog missions are under consideration to understand long-duration deep space hazards to the human system. Those hazards include isolation and confinement, altered gravity fields, communication delays due to distance from Earth, and hostile environments. NASA will continue to work with other governmental agencies to ensure that research activities are complementary and not overlapping. Life Sciences highest fundamental research priorities are plants and microbiome of the built environment. Physical Sciences highest fundamental research priorities are combustion and phase change-associated energy transfer. Mr. Scimemi reviewed charts showing the 2017 mid-term Decadal survey research priorities critical to the expansion of human exploration into deep space. He noted that astrophysics, heliophysics, planetary, and Earth sciences would continue to find uses for a LEO platform in addition to dedicated spacecraft.

Mr. Tommy Holloway commented that finding a private company to take over responsibility for LEO research administration would be difficult. Mr. Scimemi responded that there is no intention to have commercial industry take over all research administration; rather, the proposal is to use a private contractor to execute NASA's roles as much as feasible. Mr. Holloway advised that transportation costs would remain a large problem. Mr. Scimemi replied that NASA would always pay for its share. In response to a question from NAC Chairman Gen. Lester Lyles, Mr. Scimemi explained that NASA would be using the NRA process to "scour the whole breadth of national labs" for a business model and pay attention to industry's proposals. Mr. Wayne Hale asserted that there would be a problem because the Administration is proposing "no further funding from the government." Mr. Scimemi clarified that while the government would end direct funding of the ISS, it would pay a contractor to operate the ISS or other LEO platform and provide services needed by NASA. Mr. Gerstenmaier explained that the reason for the NRA is to obtain market information on how private contractors would do the work,

which up to now has been all speculation. Mr. Holloway advised that contractors need to understand what NASA would be willing to pay for; "otherwise, you will get a phony-baloney analysis." Mr. Gerstenmaier responded that he wants to see what their business plans would be. Mr. Holloway stated, "at the end of the day they will want to know how much the government is willing to pay to subsidize the deal." Mr. Scimemi added "this is a step-by-step approach, we have time."

Mr. Mark McDaniel thanked Mr. Scimemi for an outstanding report and asked how the public can learn about the work that is being done. Mr. Scimemi responded that there is NASA TV and the NASA webpage; however, NASA does not have legislative authority to advertise. Mr. McDaniel noted that many poor people in the U.S. do not have access to that information and that the NASA logo is the most recognized logo in the nation. Mr. Scimemi responded that another information source is Spinoffs, a NASA online publication. Dr. Patricia Sanders, NASA Aerospace Safety Advisory Panel (ASAP) Chair, observed that the publication would only be found by people who are looking for it. She added that the Center for the Advancement of Science in Space (CASIS), which is the manager of the ISS National Laboratory, is not subject to the same advertising limitations as NASA. Mr. Scimemi responded that CASIS has budget constraints and is not permitted to lobby Congress. Gen. Lyles noted that NASA Administrator Jim Bridenstine recently announced the formation of a new NAC committee that will examine regulatory and policy issues. He suggested that the new committee could examine regulatory constraints in disseminating information.

Mr. Bowersox thanked Mr. Scimemi for his presentation.

Exploration Systems Division

Mr. Bowersox introduced Mr. Bill Hill, Deputy AA for Exploration Systems Development (ESD). Mr. Hill briefed the Committee on Exploration Mission (EM)-1. It is the first uncrewed, integrated flight test for NASA's Orion spacecraft and SLS rocket, which will be launched from a modernized KSC spaceport. He explained that the mission's trajectories will include a Distant Retrograde Orbit (DRO) 37,000 miles from the surface of the Moon and an orbit 62 miles from the lunar surface.

Mr. Hill reviewed work that has been accomplished and work that remains for EM-1. Flight software verification testing at the Integrated Test Laboratory (ITL) is scheduled to be completed in August 2019. He described the Launch Abort System (LAS) Crew Module Adapter (CMA) and the European Service Module (ESM), which are scheduled to be mated in October 2018. The Interim Cryogenic Propulsion Stage (ICPS) was delivered to KSC in July 2017 and is being stored in the Space Station Processing Facility (SSPF). The Orion Stage Adapter (OSA) was delivered to KSC in April 2018. The Launch Vehicle Stage Adapter (LVSA) is scheduled to be delivered to KSC in October 2018. Mr. Hill presented a graphic showing the EM-1 SLS rocket stages: the forward skirt, liquid oxygen (LOX) tank, intertank, liquid hydrogen ($LH_2$) tank, and engine section. The EM-1 boosters are scheduled to be shipped to KSC in February 2019. Four EM-1 RS-25 engines were delivered-in-place in October 2017. In response to a question from Mr. James Voss, Mr. Gerstenmaier explained that the solid rocket boosters would remain stable for at least five years when kept in storage. Mr. Hill presented a slide on software testing at the NASA Marshall Space Flight Center (MSFC) Software Integration Test Facility (SITF) that is scheduled to be completed in January 2019.

Mr. Hill presented a graphic showing the planned EM-2 trajectory. It is a crewed, hybrid free-return trajectory. EM-2 will demonstrate crewed flight and spacecraft systems performance beyond LEO. It will fly around the Moon at 4,800 miles from the lunar surface and return to Earth at Mach 32. He described the progress that has been made on the EM-2 Orion spacecraft and the EM-2 SLS.

Mr. Hill discussed the status of Exploration Ground Systems (EGS). The Interim Cryogenic Propulsion Stage Umbilical (ICPSU) and Crew Access Arm (CAA) for the Mobile Launcher (ML) are being tested at the KSC Launch

Equipment Testing Facility (LETF). All vehicle access platforms for EM-1 have been installed in the KSC Vehicle Assembly Building (VAB). Testing on the ECLSS is scheduled for completion in September 2018. He reviewed a slide showing the status of work at KSC Pad 39B for EM-1 and EM-2. He discussed the KSC Multi-Payload Processing Facility (MPPF) where Orion will be fueled. Mr. Hill described the Spaceport Command and Control System (SCCS) and the status of Ground Flight Application Software (GFAS).

Mr. Hale noted that he has been informed that the software is on schedule but cautioned that software development must be watched carefully. He predicted that it would become the "long pole in the tent."

Mr. Bowersox thanked Mr. Hill for his presentation.

Commercial Crew and Launch Readiness Process

Mr. Bowersox introduced Ms. Kathryn Lueders, CCP Manager, who briefed the Committee on the Program's status. She reported that the CCP has made significant progress over the last quarter. Mission planning and preparations for eight CCP missions are underway. SpaceX will launch a flight to the ISS without crew in November 2018. It will launch a crewed mission to ISS in April 2019. Boeing will conduct an Orbital Flight Test in late 2018 or early 2019, and a Crewed Flight Test in mid-2019. Both providers are meeting contractual milestones and maturing their designs. A significant amount of hardware is being developed, tested, and qualified in preparation for upcoming missions. Risks are being identified, important design challenges are being addressed, and NASA is engaged in meaningful insight. She explained that CCP has robust and efficient processes for certification, including addressing waivers and deviations. Progress is being made in the burn-down of key certification products with the providers. Crew members have been assigned to missions. Interagency work continues to enable the commercial spaceflight industry.

Ms. Lueders presented a graphic showing steps taken and remaining on the timeline for commercial crewed flights to the ISS. She described the nine U.S. astronauts who have been assigned to fly the four initial test flights and post certification missions to the ISS aboard America's first commercially built spacecraft. One astronaut is provided by Boeing and the others are provided by NASA. The Boeing astronaut will join two NASA astronauts on the Boeing Crewed Flight Test. Mr. Voss commented that a third crew member is not necessary on that flight, and he expressed concern that adding a third crew member unnecessarily increases the risks. Ms. Lueders responded that the CCP has performed a risk assessment on that issue and would look at it again. Mr. Bowersox noted that the plan is to eventually swap seats with the Russians on Soyuz and have their astronauts fly on CCP missions. He asked when that would begin. Mr. Gerstenmaier responded that it would not begin until Post-Certification Mission 1. In response to a question from Mr. McDaniel, Ms. Lueders responded that Boeing astronauts are paid more than NASA astronauts, and all astronauts are subject to the same training and requirements.

Ms. Lueders discussed Boeing's accomplishments and described the production status for Boeing Spacecraft Nos. 1, 2, and 3. She reviewed the production status for the Atlas V vehicles that will be used to launch the Boeing spacecraft. She discussed SpaceX's accomplishments and described progress made on Dragon, Falcon 9, and SpaceX's In-Flight Abort Test. Ms. Lueders described the flight operations reviews and simulations being conducted by both providers. She described the successful SpaceX dry run of Day-of-Launch Closeout Crew procedures with representative crewmembers and spacesuits. Mr. Bowersox commented that the heads of SpaceX and Boeing might want to participate in the launch activities. Ms. Lueders responded that the CCP would keep the tactical team as lean as possible. Mr. Gerstenmaier added that there would be one overall management and outside agency simulation. In response to a question from Mr. Michael Lopez-Alegria, Ms. Lueders explained that the first crewed flights would dock automatically but the crew would be trained on simulators to conduct manual docking if necessary. Mr. Gerstenmaier added that margin limitations on batteries

and other systems make it difficult to conduct numerous rendezvous "redos." Those limitations would be relaxed in the future as the requirements for docking become better understood.

Ms. Lueders discussed the Commercial Space Capabilities Collaboration (CSCC) Space Act Agreement (SSA) with Blue Origin. It provides for technical and data exchanges. She described the Commercial Crew Integrated Capabilities (CCiCap) SAA with Sierra Nevada Corporation. The company recently conducted a successful uncrewed Dream Chaser engineering test article (ETA) approach and landing test (ALT)-2 at the Armstrong Flight Research Center on Edwards Air Force Base.

Ms. Lueders concluded her presentation by discussing a slide showing how the CCP facilitates interagency, intergovernmental, and international partnerships, agreements, and legislation, with the strategic goal of enabling the commercial space industry. She noted that CCP is learning how to transition from a NASA mission to a mission licensed by the Federal Aviation Administration (FAA), and she noted that the National Transportation Safety Board (NTSB) would be part of mishap planning. She added that liability, insurance, and risk acceptance make up the framework for understanding the commercial business case.

Mr. Bowersox thanked Ms. Lueders for her presentation.

Gateway Power Propulsion Element Update

Mr. Bowersox introduced Dr. Michele Gates, PPE Director, HEOMD, who briefed the Committee on the status of the PPE for Gateway. Dr. Gates summarized information she provided to the Committee at its last meeting. She reviewed recently completed PPE milestones and presented a graphic showing a timeline for the NASA Exploration Campaign.

Dr. Gates discussed the approach to PPE development. It will be the first Gateway element and is targeted for launch readiness in 2022. In response to a question from Mr. Voss, Dr. Gates stated that the schedule would allow for a 36-month development and test schedule. Mr. Voss expressed concern over whether the schedule was viable. Mr. Bowersox commented that communication satellites require 24 months for development and testing. Mr. Gerstenmaier noted that a commercial satellite bus could be augmented with solar electric propulsion (SEP). Dr. Gates explained that PPE leverages advanced SEP technology with U.S. industry's current capabilities through a public-private partnership. PPE will provide power for communications, transportation, controls, and future Gateway elements. PPE will be launched on a partner-provided commercial rocket and will be the first module in lunar orbit for Gateway. The PPE will allow passive docking using an International Docking System Standard (IDSS)-compliant interface and enable Gateway to move to various lunar orbits. It will have a 2-ton xenon propellant capacity, be refuelable, and have an expected 15-year lifespan.

Dr. Gates described U.S. industry-led studies for a SEP vehicle capability. NASA has issued a Draft Broad Agency Announcement (DBAA) for a PPE spaceflight demonstration. The DBAA seeks creative and innovative proposals from industry for the spaceflight demonstration of one or more PPEs through a public-private partnership to meet the desired objectives and performance requirements of both partners. The DBAA's only unique requirement is the specific functionality that PPE must provide as the first Gateway element. That is intended to permit industry to propose a bus and spacecraft that would also meet industry's needs for future commercial spacecraft applications. The private partner will own the PPE through the first year of the spaceflight demonstration. NASA will have an option to own the PPE to support Gateway at the completion of the demonstration. Offerors' proposals must identify the profit potential from proposed future PPE-derived products and show how proposed commercial objectives could be achieved by the demonstration. Dr. Gates noted that NASA is committed to stable PPE requirements, minimal requirement changes, streamlined reporting, and an insight-only approach to contract management focused on understanding risk.

In response to a question from Ms. Ruth Gardner, Dr. Gates explained that PPE would need to be in place before EM-3 and be owned by NASA prior to crew arrival. Mr. Gerstenmaier noted that it is a test with a one-year margin and that "NASA is giving private industry an opportunity to deliver." He stated, "We have opened up the aperture as wide as we possibly can and are looking forward to seeing what industry can do." Dr. Gates explained that NASA intends to exploit the shared risk and reward model. In response to a question from Mr. Hale, Mr. Gerstenmaier explained that the Program has had discussions with NASA's independent technical authorities. He noted that Gateway does not have to be human rated because Orion would always be available to return crew to Earth. He added "this is an excellent test case to see how far we can rely on commercial development."

Dr. Gates described a recent PPE Industry Day with 62 participants from 21 companies. She reported that overall industry feedback to the DBAA was very positive and would help NASA finalize its approach. She described other recently completed PPE external events.

Dr. Gates discussed the various lunar orbits for the PPE after it is turned over to NASA for Gateway. She explained that the PPE in lunar orbit could be used to support missions to the lunar surface and its vicinity as well as serve as a staging point for sample return missions. She presented a chart showing the advantages of SEP compared to chemical propulsion.

Dr. Gates presented slides on STMD's progress on high-power, high-throughput electric propulsion technology development. She concluded her presentation by describing upcoming PPE events.

Mr. Bowersox thanked Dr. Gates for her presentation.

Public Comments

Mr. Bowersox invited comments from the public. Mr. Robert Zimmerman introduced himself and thanked the presenters for wonderful presentations. He explained that he had helped to develop NASA's technical and life support systems. He suggested that consolidating information about economic benefits flowing from NASA's programs would make that information more easily accessible and available to the public. He also suggested that NASA, for itself and the public, should make it easier for the public to search for intellectual property developed with NASA funding. He offered to assist in making that information easier to access.

Discussion and Recommendations

Mr. Bowersox explained that the Committee's findings and recommendations can go to either the Administrator or the AA and must be approved by the full NAC. Committee conclusions and observations do not require NAC approval. As an example, he noted that Gen. Lyles had previously requested a Finding for consideration by the NAC based on a Committee observation concerning the status of ISS after 2014.

Mr. Bowersox reviewed the Committee's recommendation from its last meeting. He asked the Committee members for their suggestions on findings and recommendations. Mr. Levin suggested that patent applications and their value could be used as a metric. Mr. McDaniel noted that NASA is on the "cutting edge of law" due to mixing NASA astronauts with private industry astronauts. Ms. Nancy Ann Budden suggested encouraging NASA to seek additional resources to satisfy the President's new goal to return to the Moon. Mr. Hale questioned whether Gateway is the right next step and whether NASA should be building lunar landers instead. Mr. Voss agreed with Mr. Hale and advised that all the pieces for returning to the Moon had to be "put in place today." Mr. Holloway requested the compelling reasons for Gateway's construction, rather than saving the money and going to the Moon and Mars. He also cautioned that "the ISS transition is a complicated problem and will cause misery if NASA isn't careful."

Mr. Bowersox reviewed the Committee's observations and concerns from its last meeting. He noted that Gateway takes an in-depth knowledge to understand why it makes sense. Dr. Condon concurred and commented "it is not easy to see how the dots are connected." He added that lunar activities as well as Gateway make sense for Mars. Gen. Lyles noted that Mr. Bridenstine wanted to know the NAC's opinion on Gateway. Mr. McDaniel commented that Gateway is important for going to the Moon and Mars. Dr. Sanders advised that Gateway provides risk reduction for exploring the Moon and Mars. Mr. Bowersox noted that the Committee had previously endorsed Gateway. Mr. Lopez-Alegria observed that NASA did not have funds for putting man back on the Moon's surface, and Gateway is a good step at this time. Mr. Voss stated that Gateway would be an enabler for exploration. Mr. Bowersox commented that NASA should be aggressive in requesting resources for executing the President's space policy directives. Dr. Condon observed that NASA would never get anywhere if it keeps changing direction with every change in administration, and there is a need for NASA's vision to transcend administrations. Mr. Bowersox concurred and stated that that is one of the most important issues for NASA to address. Dr. Sanders observed that NASA no longer has as large a discretionary budget as it used to have. Mr. Hale stated, "we don't want to repeat flags, footprints, and not going back for 50 years." Mr. Gerstenmaier advised that an augmented budget would be necessary for returning to the Moon. Mr. Levin observed that there are positive signs showing that the engagement of industry has begun. After further discussion, the Committee agreed to revise its observations and concerns to read as follows:

HEO Committee Observations

- NASA has set forth a clear set of principles to guide its ISS transition plan for 2024 and beyond, and submitted a report on ISS transition to congress. The committee looks forward to reviewing the responses from industry to NASA's most recent request for information on ISS transition. At this meeting the committee was informed that 68 patent applications have been filed based on work at ISS – this is the type of metric that would be very useful to inform decisions on economic value during ISS transition.
- The Committee is encouraged to see the level of support from the president and congress for NASA's sustainable approach to human exploration beyond low earth orbit as evidenced by the president's space policy directives, the most recent NASA authorization act, as well as the 2018 and 2019 NASA budgets. It will be exciting for the committee to monitor and review plans for returning humans to cislunar space and to the surface of the moon as they are developed over the next year. The committee is especially eager to see future plans for landing and operating on the lunar surface as soon as they are ready to be reviewed.
- The committee members support NASA's plans for a lunar orbiting platform that will enable international and commercial partnerships, reusability of hardware to transport crews to and from the lunar surface, reduce risk for lunar exploration crews by providing a safe haven, improve communications with spacecraft on the lunar surface, and provide valuable opportunities for scientific investigations, while expanding the knowledge base in the area of deep space maneuvering and solar electric propulsion required for travel to Mars.
- The approach and flexibility displayed by NASA in its commercial cargo program is resulting in the provision of essential services at a cost lower than previously possible. Whenever appropriate, NASA's other human exploration programs should be allowed to take advantage of the flexibility which has made the ISS commercial cargo delivery effort so successful. For example, allowing the SLS and Orion programs additional programmatic flexibility could be helpful as they continue to evaluate options for increased flight rate.

HEO Committee Concerns

- As the Commercial Crew Program, SLS and Orion finish their development phases and transition toward operations, NASA's approach to program governance may unnecessarily slow the resolution of critical issues as they make their way through the programs and independent technical authorities for final resolution.
- NASA has been working with their Russian partners to maximize the on orbit stay time for Soyuz vehicles which will ensure US crew presence at ISS through January of 2020. If operational availability of commercial crew vehicles for station crew rotation is delayed beyond January, 2020, US crew presence aboard ISS could be lost. The ISS and Commercial Crew programs are continuing to look for ways to keep US crew members aboard ISS, if the first commercial crew flights are delayed.
- Low SLS and Orion Launch rate pose future risks for proficiency of the operations team and reduce program resilience in the event of mission failure.
- Shifting priorities may result in the reduction of government funding for the ISS before a viable U.S. commercial follow-on capability is established. This capability is critical to allow NASA continued access to low Earth orbit for research, deep space exploration system testing, and other applications that may arise.
- The current HEOMD organization is working well due to its strong management team and also due to the synergy that comes from having exploration development and operations in the same mission directorate. Efforts to reorganize HEOMD at this time could increase the risk level of NASA's human exploration programs, especially considering the large amount of critical engineering work that must be completed prior to the first launches of the Commercial Crew vehicles, SLS and Orion.

Mr. Bowersox reviewed the Committee's special topics for future meetings. He noted that HEOMD's public outreach strategy would be a good topic to add to the list. Mr. Hale requested a report on lessons learned from the CCP. Mr. Voss suggested hearing the perspective from the commercial crew contractors. Gen. Lyles noted that the National Space Council had sent a list of questions to its User's Advisory Group. Mr. Bowersox stated that he would circulate the list to Committee members. Ms. Budden offered to draft a proposed Committee action approving HEOMD's phased approach and advising NASA to aggressively pursue resources. Dr. Sanders encouraged using findings rather than observations. Mr. Bowersox, after polling Committee members, determined that there was a consensus for specifically approving Gateway. After further discussion, the Committee approved the following special topics for future meetings:

- Future Special Topics:
  - International Participation in future human exploration
  - ISS after 2024 and ISS commercialization efforts ***
  - Deep space telescopes and possible servicing missions
  - Planetary Protection
  - Program decision making approach and independent technical authorities
  - Exploration EVA Capability
  - HEO External Review Summary
  - SLS and Orion activities to increase launch rate
  - Mars Transport Maintenance, Parts Commonality and Redundancy Strategy
  - Lunar Orbital and Surface Operations – Science and Exploration (Discussed at this meeting)
  - Commercial Participation in future human exploration
  - Communication of NASA's plans for Human Exploration

Dr. Siegel adjourned the committee meeting for the day at 5:00 p.m.

***Tuesday, August 28, 2018***

NAC HEO COMMITTEE / SCIENCE COMMITTEE JOINT PUBLIC MEETING

Opening Remarks for Joint Session

Dr. Siegel convened a joint meeting of the HEO Committee and the Science Committee (SC) at 9:00 a.m. She introduced Mr. Bowersox and Ms. Elaine Denning, SC Executive Secretary. Ms. Denning announced that the meeting was a FACA meeting and, therefore, would be open to the public. Minutes would be taken and posted online, along with the presentations. Ms. Denning explained that the committee members were Special Government Employees (SGEs) and subject to statutory ethics requirements. Any committee member with an ethics question should notify Ms. Denning or Dr. Siegel. There would be an opportunity for the public to make comments towards the end of the meeting, and all questions and comments from the public should be held until that time.

Ms. Denning introduced Dr. Wadhwa, SC Interim Chair. Dr. Wadhwa welcomed everyone to the meeting. She introduced Mr. Bowersox, who thanked everyone from Ames for their assistance in making it a successful meeting. At his request the committees' members introduced themselves.

Science Mission Directorate Cislunar Activities Overview

Mr. Bowersox introduced Dr. Thomas Zurbuchen, Science Mission Directorate (SMD) AA, who provided an overview of SMD, including planned cislunar activities. Dr. Zurbuchen explained that SMD has an integrated program that enables great science spanning Earth science, heliophysics, astrophysics, and planetary science. SMD's purpose is to do science and to inspire. The directorate's work is organized around the three key science themes of:

- protect and improve life on Earth,
- discover secrets of the universe, and
- search for life elsewhere.

Dr. Zurbuchen presented a graphic of the current and future science fleet, noting that SMD has 105 operating missions. He described how SMD science benefits exploration, explaining that "where we go with humans, we go with science first." Dr. Zurbuchen presented a graphic showing the science instruments attached to the ISS. He described how science uses the ISS and remarked that the platform has exceeded all expectations.

Dr. Zurbuchen discussed several SMD missions. The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) measures the temperature of plants on Earth and uses that information to better understand how much water plants need and how they respond to stress. The Lunar Reconnaissance Orbiter (LRO) is a NASA robotic spacecraft currently orbiting the Moon. LRO has supported exploration and science objectives and will continue to do so. The Mars 2020 rover mission will seek signs of habitable conditions on Mars in the past and will also search for biosignatures from past microbial life. Dr. Zurbuchen declared "in my lifetime, I want our footprints on Mars." He noted that humanity's record of successful Mars landings is only 40 percent.

Dr. Zurbuchen introduced Mr. Steven Clarke, SMD Deputy AA for Exploration. Mr. Clarke explained that his role is to develop and integrate a strategy to enable Moon and Mars robotic and human exploration through cross-agency collaboration with SMD, HEOMD, STMD, NASA field centers, and commercial, interagency and international participation, where appropriate. He is responsible for identifying potential interdisciplinary

research and technology opportunities, including commercial partnerships, necessary for NASA's Exploration Campaign.

Mr. Clarke discussed the transformative lunar science white paper in which scientists associated with the Solar System Exploration Research Virtual Institute (SSERVI) identified key areas of lunar science based on the last National Academies decadal survey :

- establish the period of giant planet migration,
- provide an absolute chronology for solar system events,
- use accessible vantage from the lunar far side to view the universe,
- understand sources of water and cycles,
- characterize the lunar interior, and
- evaluate plasma interactions with surfaces.

Mr. Clarke reviewed how CubeSat technology has matured. He presented a slide showing a CubeSat, the Lunar Polar Hydrogen Mapper (LunaH-Map). He discussed Gateway and noted that SMD has been in discussions with HEOMD on using Gateway as a platform for externally mounted science instruments. He described a draft procurement for Commercial Lunar Payload Services (CLPS), which would be used to acquire lander services to the lunar surface. Contractors would provide all services necessary to safely integrate, accommodate, transport, and operate NASA payloads on the lunar surface using contractor-provided assets.

Mr. Clarke noted that he is working with all of the science divisions in SMD to enable cross-disciplinary science around and on the Moon. He described the Apollo Next-Generation Sample Analysis (ANGSA) solicitation, which seeks research on specially curated materials from Apollo sample collections. He explained that it has been years since an Apollo-era sample was opened and new samples are needed. Mr. Clarke discussed the NASA Exploration Campaign and reviewed a chart showing the timeline for those missions through 2030. He concluded his presentation with a graphic showing important Exploration events through 2024. Dr. Vinton Cerf asked what would be learned about precision landing. Mr. Clarke responded that precision landing will continue to be refined, and lessons would be learned about collision avoidance and autonomous landing.

Mr. Bowersox thanked Dr. Zurbuchen and Mr. Clarke for their presentations.

<u>HEOMD Cislunar and Gateway Overview</u>

Mr. Bowersox introduced Mr. Gerstenmaier, who provided an overview on Gateway in cislunar space. Mr. Gerstenmaier reviewed Space Policy Directive-1 and noted that it has "created an urgency" for HEOMD. He reviewed HEOMD's strategic principles for leading future exploration. HEOMD sees science going first and helping exploration. The LRO has provided important information on radiation. Mars radiation is about the same as on the ISS; however, the thin Mars atmosphere provides some shielding. The Mars Oxygen In-situ Resource Utilization (ISRU) Experiment (MOXIE) will demonstrate how future explorers could produce oxygen from the Martian atmosphere for propellant and for breathing. Mr. Gerstenmaier noted that the delta velocity and ascent vehicles for the Moon and Mars are about the same. He explained that it is important to work with international partners and for NASA to lead the way. After 18 years on the ISS, the U.S. needs to continue its presence in space. He presented the "swoosh" graphic showing the path to the lunar surface.

Mr. Gerstenmaier introduced Mr. Jason Crusan, Director, AES and Gateway Formulation Lead. Mr. Crusan presented a graphic showing Gateway in lunar orbit. He reviewed Gateway's objectives, which are:

- NASA shall establish a Gateway to enable a sustained presence around and on the Moon and to develop and deploy critical infrastructure required for operations on the lunar surface and at other deep space destinations.

- The Gateway shall be utilized to enable human crewed missions to cislunar space, including capabilities that enable surface missions.
- The Gateway shall provide capabilities to meet scientific requirements for lunar discovery and exploration, as well as other science objectives.
- The Gateway shall be utilized to enable, demonstrate, and prove technologies that are enabling for lunar missions and that feed forward to Mars as well as other deep space destinations.
- NASA shall establish industry and international partnerships to develop and operate the Gateway.

Mr. Crusan presented a graphic showing the Gateway layout and discussed how its elements would be assembled. The elements are the PPE, a U.S. utilization module, a habitation module, the European System Providing Refueling Infrastructure and Telecommunications (ESPIRIT) module, a robotic arm, a logistics module, an airlock for EVAs, and a sample return vehicle, which is a robotic vehicle for delivering small samples or payloads from the lunar surface to Gateway. An EVA airlock is included because some repair EVAs are anticipated. Gateway assembly, however, will not require any EVAs.

Mr. Bowersox requested information on the progress that has been made in obtaining contributions from international partners. Mr. Crusan responded that international partners will "step up over time." Mr. Cerf asked whether Gateway could be assembled in an order different from that shown in the graphic. Mr. Crusan explained that there is not much flexibility due to the need to properly sequence the assembly. Mr. Gerstenmaier noted that there would be attachment points for science instruments outside of each element. He added that Gateway would be human-tended; however, it would be robotically maintained during long periods when no humans would be on board.

Mr. Crusan explained that the PPE would be the first module in lunar orbit for Gateway. PPE will provide power for communications, transportation, controls, and future Gateway elements. PPE will be launched on a partner-provided commercial rocket and will be the first module in lunar orbit for Gateway. The PPE will allow passive docking using an International Docking System Standard (IDSS)-compliant interface and enable Gateway to move to multiple lunar orbits. It will have a 2-ton xenon propellant capacity, be refuelable, and have an expected 15-year lifespan. Mr. Crusan discussed U.S. habitation module development partnerships and presented graphics showing current design concepts. He noted that providers had been requested to provide designs that would serve their own goals and that the future purchase by NASA would be based on performance standards. Dr. Cerf jovially asked whether hoteliers had been contacted to see if a honeymoon module might be designed. Mr. Crusan responded that they had not been contacted.

Mr. Crusan discussed Gateway's orbit. He noted that cislunar space offers innumerable orbits for consideration, each with merit for a variety of operations. Gateway will support missions to the lunar surface and serve as a staging area for exploration further into the solar system, including Mars. There are three orbit types: low lunar orbits that are difficult to maintain, DROs, and the fuel-efficient, near-rectilinear halo orbit (NRHO). He presented a graphic showing a NRHO 1,500 km at its closest to the lunar surface and 70,000 km at its farthest. The change in velocity (delta-v) needed to modify an NRHO orbit is not very much; however, it takes time – up to 160 days. Mr. Gerstenmaier noted that the NHRO orbit has more advantages than the other orbits and that universities would be studying lunar gravity wells and orbital mechanics to better understand those orbits. Dr. Clark commented that an NHRO orbit is not the optimal orbit for science, the orbits can be "tweaked," and the key is finding the "sweet spot" for human and science objectives.

Mr. Crusan explained that Gateway will serve as a spaceport for human and robotic exploration of the Moon and beyond and be used for human access to and from the lunar surface, cargo resupply, sample return, science and technology demonstrations, and as a communications relay. Gateway will have about 10 percent of the ISS's pressurized volume and support 4 crewmembers on 30- to 90-day crew missions. It will provide 125 cubic

meters ($m^3$) of pressurized volume, weigh up to 75 metric tons with Orion docked, and orbit 384,000 km from Earth. It will be accessible via the SLS as well as international and commercial ships.

In response to a question from Mr. Bowersox, Mr. Crusan explained that Gateway will have two or three ports. Mr. Bowersox commented that a visiting Mars-class vehicle would be very large. Dr. Tamara Jernigan asked Mr. Crusan what keeps him up at night. He responded that he is most concerned about moving forward very quickly on a very challenging program. He added that orbital mechanics must be learned again. Mr. Bowersox asked whether the Russians were interested in flying vehicles to Gateway. Mr. Crusan responded that there is nothing to prohibit them from doing so with a crewed vehicle of their own. Mr. Gerstenmaier noted that there are many areas for contribution by international partners, particularly with respect to the lunar surface. He added that it is important to keep Gateway small and to build it quickly. Mr. Crusan noted that many international partners have a strong interest in the lunar surface. In response to a question from Dr. Wadhwa, Mr. Crusan stated that interoperability requirements will be published and available to potential new partners. Mr. Gerstenmaier added that orbital studies will be made available to the international community. In response to a question from Dr. Pat Patterson, Mr. Crusan stated that there have been discussions about using Gateway for small CubeSat deployments. Mr. Bowersox asked how traffic around Gateway would be managed. Mr. Crusan responded, "we will have to start thinking about standards for that." Mr. Bowersox expressed concern about creating a debris cloud around the Moon, because there is no atmosphere to drag the debris down to the surface; it would stay in orbit forever.

Mr. Bowersox thanked Mr. Gerstenmaier and Mr. Crusan for their presentations.

Gateway Science Workshop Outcomes

Dr. Wadhwa introduced Mr. John Guidi, Director, AES, HEOMD. Mr. Guidi described four focus areas for Gateway utilization:

- identify high-priority technologies for Gateway demonstrations,
- develop an overall commercial strategy for Gateway,
- enable collaboration between interested international parties, and
- identify potential science opportunities and how Gateway infrastructure can support science investigations.

Mr. Guidi presented a graphic on Gateway utilization locations. All Gateway elements will have external payload accommodations except for inflatable concepts, which are under study. All pressurized volumes may have internal payload accommodations.

Mr. Guidi discussed results from the Deep Space Gateway Concept Science Workshop recently held in Denver, Colorado. The workshop was sponsored by HEOMD, SMD, NASA's Johnson Space Center (JSC), NASA's MSFC, and NASA's Goddard Space Flight Center (GSFC). The rationale for the workshop was to engage the science community on Gateway's science potential, discuss potential scientific investigations that leverage Gateway, and discuss the resources that Gateway should provide to facilitate different scientific investigations. There were 300 attendees. The sessions covered heliophysics, Earth science, astrophysics, fundamental physics, lunar and planetary science, life sciences, and space biology. Cross-cutting discussions were held on orbits, human exploration, space weather, external instruments, samples, telerobotics, and internal instruments. Abstracts were submitted proposing 220 investigations. Mr. Guidi described the top takeaways from the workshop. He reviewed analytical charts analyzing science utilization requirements developed from the workshop for upmass, electrical power, internal volume, and daily data.

Mr. Guidi described international Gateway science-focused events conducted by the European Space Agency (ESA), the Canadian Space Agency (CSA), and the Japanese Space Agency (JAXA). Each agency is participating in

the Gateway design and development process. He reviewed key lessons learned from those events. There should be a focus on obtaining support from specific science stakeholder communities, rather than seek broad support. Science utilization requirements should be included in program goals. A new accommodation, other than express racks, for internal experiments should be considered. Science among Gateway users and partners should be prioritized. Mr. Guidi concluded his presentation by describing near-term science utilization activity. Those activities include GPS navigation on Gateway, Gateway usage during uncrewed periods, locating experiments externally, logistics, external arm delivery, and studies by the Space Life and Physical Sciences Research and Applications (SLPSRA) Division to identify potential science experiments and common laboratory facilities.

Dr. Wadhwa thanked Mr. Guidi for his presentation and introduced Dr. Sarah Noble, a planetary scientist in SMD. Dr. Noble described the 2007 National Research Council (NRC) report entitled "The Scientific Context for the Exploration of the Moon (SCEM)" that identified a set of science goals and priorities for lunar science. She noted that a decade of intensive lunar science research has led to substantial progress in many areas, but the concepts, goals, and priorities of the 2007 NRC report remain relevant today and provide important context in a prioritized framework for advancing lunar and solar system science. Dr. Noble presented a slide showing the SCEM concepts. She discussed in detail the progress that has been made on the five goals for SCEM Concept 3, which states "Key planetary processes are manifested in the diversity of lunar crustal rocks." She explained that further progress on many SCEM goals would require lunar surface missions and geological fieldwork by astronauts.

Dr. Noble reviewed findings by the Next Steps on the Moon Special Action Team (NEXT-SAT). There are numerous options for lunar missions to make paradigm-shifting advances in planetary science. Commercial entities should be used to increase competition, decrease costs, and increase the flight rate. With NASA as a customer, there are many opportunities for commercial services in lunar surface exploration. Future mission teams should leverage targeting from LRO instruments to ensure that data for site selection certification is available. Dr. Noble described NEXT-SAT investigations addressing key science questions. She discussed orbital missions, impactors, relay satellites, navigational aids, CubeSats, and small satellites. Dr. Noble contrasted missions using fixed, stationary landers and mobility-desired missions using rovers and hoppers. She described sample return missions, as well, and presented a graphic showing proposed targets for those missions across the lunar surface.

Dr. Noble discussed a workshop held last winter on lunar science for landed missions in which eight lunar commerce companies participated. The workshop report can be found at https://lunar-landing.arc.nasa.gov. She concluded her presentation with a graphic showing potential sites for lunar science landed missions.

Dr. Wadhwa thanked Dr. Noble for her presentation.

Transformative Lunar Science

Dr. Wadhwa introduced Dr. Nicolle Zellner, Professor of Physics at Albion College in Michigan and lunar impact glass expert. Dr. Zellner presented her research on rethinking solar system bombardment and new views on the timing and delivery of lunar impactors. She explained that the lunar cratering rate anchors the impact chronology for the entire inner solar system. Lunar samples and the lunar surface are mostly undisturbed by geological processes. Lunar samples can be dated. High-resolution photographs enable craters to be counted to determine the lunar impact flux. The lunar impact flux is a potentially important factor for affecting biotic evolution on Earth.

Dr. Zellner described lunar impact glasses, which are formed when surface regolith is melted during a high-temperature event. Regolith is a fine powder formed from impacts over billions of years. The composition, age,

and shape of impact glasses are useful tools to extract information about impact flux. She described the impact mechanism and the lunar cataclysm theory. Views about the theory's validity have changed due to new data from the LRO and new interpretations about samples due to more data and more sophisticated analytical techniques. Dr. Zellner presented a chart showing new data from the Lunar Orbiter Laser Altimeter, an instrument on the LRO. She reviewed a chart on updated crater age calculations based on re-calibrated sample ages and how orbital data is providing higher resolution images of super-positioning of ejecta blankets. She described new dynamical models and discoveries of terrestrial Archean impacts. These have led to the conclusion that the late heavy bombardment (LHB) period lasted much longer than previously thought. Dr. Zellner presented a slide showing new data from NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission. The data indicates that the impact flux needs to be recalibrated because the number of impactors that could form basins decreased substantially through the Nectarian and Imbrian periods.

Dr. Zellner observed that China, India, Japan, ESA, and the U.S. are interested in returning to the Moon and looking for volatiles, water, and settlement locations. China plans to land on the far side and eventually return a sample in another mission. Transformative science results from cross-disciplinary efforts that make more progress than disciplinary efforts in isolation.

Dr. Cerf asked whether there is a correlation between samples collected from asteroids and samples collected from the Moon. Dr. Zellner responded that lunar samples do contain suspected asteroidal fragments but these fragments have not been tied back to a specific asteroid, only types of asteroids. In response to a question from Dr. Walter Secada, Dr. Zellner explained that more samples would accelerate learning about lunar evolution. Ms. Budden commented that the basic reasons for going back to the Moon are compelling and have been unchanged for thirty years.

Dr. Wadhwa thanked Dr. Zellner for her presentation. She then introduced Dr. Jack Burns, Professor in Astrophysical and Planetary Sciences at the University of Colorado, who discussed transformational science from the Moon for astrophysics, cosmology, and heliophysics. He described low-frequency radio heliophysics, coronal mass ejections (CMEs), and solar type II and type III radio bursts caused by CMEs. He presented a graphic showing the Sun Radio Interferometer Space Experiment (SunRISE) Earth-orbiting array and discussed its capabilities. It will launch in 2022 if funded. Dr. Burns explained that the timing and location of solar radio bursts can be used to identify energetic particle acceleration and, therefore, has the potential to be used for providing space weather alerts. Arrays of low-frequency antennas on the lunar near side can help locate and time radio bursts associated with CMEs. He presented a chart showing the requirements for imaging solar radio bursts from the lunar surface. Dr. Burns noted that the requirements for a lunar surface radio telescope are modest. He presented a short video showing a CME.

Dr. Burns discussed extrasolar planets. Understanding the impact of stellar activity and the presence of planetary magnetic fields is becoming increasingly important for defining planetary habitability. Hydrogen cosmology from the Moon has unique potential to characterize the first stars and galaxies and to investigate dark matter in the Dark Ages. Low-frequency radio observations from the lunar far side are the key for doing this. Dr. Burns discussed Gateway and noted that it is not just a gateway to the Moon, Mars, and beyond—it can also be a gateway to the search for life in the galaxy. He described potential capabilities needed from Gateway for science. Those needs include autonomous and dexterous external robotic arms capable of assembling and servicing, berthing points for unpressurized cargo containers, astronaut EVAs, a quiescent environment, and photogrammetry instruments.

Dr. Burns noted that the Astrophysics Decadal Survey and the NASA Astrophysics Roadmap identify Cosmic Dawn and Dark Ages as a top science objective. When and how the first galaxies formed from cold clumps of hydrogen gas and started to shine is a great mystery. He discussed the Netherlands-China Low-Frequency

Explorer (NCLE) that will attempt to detect CMEs from the Sun and will serve as a precursor for future hydrogen cosmology missions and radio interferometry. He discussed the Dark Ages Polarimeter PathfindER (DAPPER), for which he is the Principal Investigator (PI). DAPPER will search for deviations from the standard model of cosmology, possibly produced by dark matter, by measuring low radiofrequency absorption.

Dr. Burns discussed low-latency, lunar-surface telerobotics. He described infrastructure that Gateway could provide for lunar robotics, including a communications relay, orbital computing – the space equivalent of "cloud computing," site maps developed from orbital mapping, position and timing calculations to assist rover localization, power beaming, remote sensing, and a sample return cache. In response to a question from Dr. Michelle Larson, Dr. Burns explained that Gateway is a better location than ISS for large-aperture telescopes because it is closer to the second Lagrange point. Dr. Burns described how a radio telescope could be assembled on the lunar far side by astronauts aboard Gateway using teleoperated rovers and 3D printers. He presented a short video on the subject. Dr. Cerf explained that in telerobotics a time delay greater than 0.5 seconds makes operations difficult. He noted that radio transmissions from Earth to the Moon take 2.5 seconds and transmissions from Gateway to the Moon would take 0.5 seconds. In response to a question from Mr. McDaniel, Dr. Burns explained that Gateway would help identify Earth-like planets, particularly with construction of a large aperture telescope.

Dr. Wadhwa thanked Dr. Burns for his presentation.

Public Comments

The public was invited to make comments. There were none.

Discussion, Findings, and Recommendations

The committees discussed potential findings and recommendations. Mr. Bowersox suggested findings on good collaboration between HEOMD and SMD, the interesting work that has been done on Gateway and returning to the lunar surface, and the importance for NASA's work to be prioritized. Dr. Cerf suggested an endorsement on the Gateway approach and its exciting possibilities. Dr. Jernigan suggested advocating for the inclusion of international partners. Per the idea that the Gateway has promise to facilitate construction of large aperture ultraviolet/visible spectrum telescopes, Dr. Scowen cautioned about whether the Gateway is pristine enough for astrophysics in terms of ultraviolet spectrum throughput. Vibration also would limit the value of optical instruments mounted on the Gateway.

Mr. Hale noted that NASA intends to follow decadal science plans rigorously. Dr. Wadhwa commented that the most imminent decadal would be in astrophysics. Dr. Paul Scowen explained that the science community has an opportunity to submit white papers that help shape the decadal prioritization. Gen. Lyles stated that he would appreciate a joint-committee finding on the balance between exploration and discovery. He also reported that the National Space Council wanted to know whether there are any policies, barriers, or regulations that preclude a good balance between exploration and science, and whether the policy of following the decadal is something that restricts NASA too much. Mr. Gerstenmaier responded that there is a natural compatibility between exploration and science activities.

Mr. Bowersox presented a proposed joint finding on the collaboration between SMD and HEOMD, the opportunities for work in cislunar space aboard Gateway, and the synergy between investigations in lunar orbit and on the lunar surface. After discussion and minor modifications, the committees approved the following joint finding:

- The NAC's HEO and Science Committees met jointly on August 28th to review plans for the development of the cislunar Gateway, some results from previous lunar science missions, and potential future exploration and science operations in cislunar space and on the lunar surface.
- The committees were impressed with the level of collaboration evident between SMD and HEOMD as well as the potential for future joint efforts.
- It was clear from the presentations at the joint session that there are many opportunities for valuable exploration and science activity in cislunar space aboard Gateway.
- It was also evident that there is great synergy between investigations that can be performed from lunar orbit and science activity on the lunar surface.
- The committees look forward to a future joint session as plans mature for science and exploration activity in lunar orbit and on the surface.

Mr. Bowersox presented a proposed joint finding on NASA's inclusion of international partners in the Gateway program. After discussion and minor modifications, the committees approved the following joint finding:

- The Joint NASA Science and Human Exploration Operations Committees applaud NASA's inclusion of international partners in the Gateway Program. The value of international cooperation goes beyond the technical synergies realized through collaborations among traditional and emerging international partners. Perhaps more importantly, space exploration, pursued as an international community, facilitates peaceful interactions at large among all participating nations.

Mr. Bowersox presented a proposed joint finding on NASA's complementary approach to exploration that balances exploration and science. After discussion and minor modifications, the committees approved the following joint finding:

- The HEO and Science Committees jointly acknowledge and applaud the direction NASA has taken toward a complementary approach to exploration, that facilitates a balance between exploration and scientific discovery. The approach includes work in LEO, cislunar space (currently envisioned as Gateway), lunar surface exploration, and deep space exploration. NASA's plans have the potential to support both HEO and Science Mission Directorate objectives and goals, while meeting the intent of Space Policy Directive-1 (SPD-1) for a return to the Moon. This concept features a role for international and commercial partners, reusability, sustainability, reconfigurable components, and builds toward the ultimate national vision for deep space exploration and science, including a crewed mission to Mars.

Mr. Bowersox presented a proposed joint observation on applying new terrestrial technologies to HEOMD and SMD missions. After discussion and minor modifications, the committees approved the following joint observation:

- The HEO and the Science Committees observe that new technologies being developed for terrestrial industries may be applied to both HEO and SMD missions, like the Gateway. For example, autonomous vehicles on Earth and space may share similar instrumentation and sensing computational capability. Developing high-resolution solid-state LIDAR, teleoperations, and new techniques for sensor fusion will be important for any autonomous vehicle on Earth or in deep space.

Mr. Bowersox presented a proposed joint recommendation on setting priorities for Gateway. After discussion and minor modifications, the committees approved the following joint recommendation:

**Title:** Use of decadal surveys and exploration objectives to set priorities for Gateway
**Recommendation:**

**For the SMD AA:** The joint committees recommend that the science initiatives implemented at Gateway should be prioritized to align with the National Academies' decadal surveys.
**For the HEOMD AA:** The joint committees recommend that the objectives for exploration initiatives enabled by the Gateway approach should be clearly articulated by HEOMD to set expectations for all stakeholders.
**Major reasons for proposing the recommendation:** The Science and Human Exploration and Operations Committees applaud the leadership of HEOMD and SMD for fostering a balance between exploration and discovery in the Gateway concept. When communicating about the Gateway concept both science and exploration should indeed be emphasized. Clearly articulated exploration objectives for Gateway and reference to science decadal surveys will be critical as requirements for Gateway are developed in order to set expectations for all Gateway stakeholders and prioritize future Gateway science activity.
**Consequences of no action on the proposed recommendation:** Failure to articulate exploration objectives and science priorities for Gateway could result in confusion amongst stakeholders and unnecessarily decrease the effectiveness of a major NASA initiative.

Adjourn

Dr. Siegel thanked everyone on both committees and the personnel at Ames for their help in making the meeting successful. She thanked the committees' support staff for their efforts. Dr. Siegel adjourned the meeting at 3:00 p.m.

# NASA ADVISORY COUNCIL
## Human Exploration and Operations Committee
**MEETING**

NASA Ames Research Center
NASA Ames Conference Center
Moffett Field, CA

***AGENDA***

**Monday, August 27, 2018**

NAC HEO COMMITTEE PUBLIC MEETING

| | | |
|---|---|---|
| 10:00 – 10:05 | Call to Order, Welcome & Opening Remarks | Mr. Ken Bowersox & Dr. Bette Siegel |
| 10:05 – 11:00 | Human Exploration and Operations Overview | Mr. Bill Gerstenmaier |
| 11:00 – 12:00 | ISS Update, Accomplishments and Future | Mr. Sam Scimemi |
| 12:00 – 1:00 | ***Lunch*** | |
| 1:00 – 2:00 | Exploration Systems Division | Mr. Bill Hill |
| 2:00 – 3:00 | Commercial Crew and Launch Readiness Process | Ms. Kathy Lueders |
| 3:00 – 3:30 | Gateway Power Propulsion Element Update | Dr. Michelle Gates |
| 3:30 – 3:35 | Public comments | |
| 3:35 – 3:40 | Break | |
| 3:40 – 5:00 | Discussion and Recommendations | |
| 5:00 | Adjourn | |

**NASA ADVISORY COUNCIL**
**Human Exploration and Operations Committee**
**MEETING**

NASA Ames Research Center
NASA Ames Conference Center
Moffett Field, CA

***AGENDA***

**Tuesday, August 28, 2018**

JOINT HEO COMMITTEE AND SCIENCE COMMITTEE PUBLIC MEETING

| | | |
|---|---|---|
| 8:00 – 8:10 | Opening Remarks | Ms. Elaine Denning<br>Dr. Meenakshi Wadhwa<br>Dr. Bette Siegel<br>Mr. Ken Bowersox |
| 8:10 – 9:15 | SMD Cislunar Activities Overview | Dr. Thomas Zurbuchen<br>Mr. Steven Clarke |
| 9:15 – 10:15 | HEOMD Cislunar Gateway Overview | Mr. William Gerstenmaier<br>Mr. Jason Crusan |
| 10:15 – 10:30 | ***Break*** | |
| 10:30 – 11:30 | Gateway and Landed Science | Mr. John Guidi<br>Dr. Sarah Noble |
| 11:30 – 12:30 | Transformative Lunar Science | Dr. Nicolle Zellner<br>Dr. Jack Burns |
| 12:15 – 1:15 | ***Joint Lunch*** | |
| 1:15 – 1:20 | Public Comments | |
| 1:20 – 2:45 | Discussion, Findings, and Recommendations | |
| 2:45 | ***Adjourn Joint Meeting*** | |

**Human Exploration and Operations Committee Membership**
**August 2018**

| | |
|---|---|
| Mr. Ken Bowersox, *Chair* | Former NASA astronaut and retired U.S. Navy Captain |
| Dr. Bette Siegel | NASA Headquarters<br>*Executive Secretary* |
| Ms. Shannon Bartell | Former Director of Safety & Mission Assurance, KSC |
| Ms. Nancy Ann Budden | Director for Special Operations Technology, Office of the Secretary of Defense |
| Dr. Leroy Chiao | Former NASA Astronaut and ISS Commander |
| Dr. Stephen "Pat" Condon | Aerospace Consultant, former Commander of the Ogden Air Logistics Center, the Arnold Engineering Development Center, and the Air Force Armament Laboratory |
| Mr. Joseph Cuzzupoli | Former Assistant Apollo Program Manager, Rockwell, and manager of the Space Shuttle Orbiter Project |
| Ms. Ruth Gardner | Technical Deputy Director, Engineering and Technology Directorate, Kennedy Space Center |
| Mr. Tommy Holloway | Former Space Shuttle and ISS Program Manager |
| Mr. Lon Levin | President, SkySevenVentures |
| Dr. David E. Longnecker | Director, Health Care Affairs, Association of American Medical Colleges (AAMC), member of the National Academy of Sciences Institute of Medicine (IOM) |
| Mr. Michael Lopez-Alegria | Former NASA astronaut and retired U.S. Navy Captain, President of the Commercial Spaceflight Federation |
| Mr. Mark McDaniel | Partner at McDaniel and McDaniel Attorneys, LLC |
| Mr. Bob Sieck | Former Space Shuttle Launch Director |
| Mr. Gerald Smith | Former Deputy Director, Stennis Space Center, Georgia Tech Research Institute, Thiokol Propulsion, National Space Science and Technology Center in Huntsville |
| Mr. James Voss | Former NASA astronaut and retired U.S. Army Colonel, Scholar in Residence, Department of Aerospace Engineering Sciences, University of Colorado, Boulder |

**Human Exploration and Operations Committee**
**NASA Ames Research Center**
**NASA Ames Conference Center**
**Moffett Field, CA**
**August 27-28, 2018**

**MEETING ATTENDEES**

| | |
|---|---|
| *HEO Committee Members:* | |
| Bowersox, Kenneth, *Chair* | Aerospace Consultant |
| Siegel, Bette, *Executive Secretary* | NASA Headquarters |
| Budden, Nancy Ann | Office of the Secretary of Defense |
| Condon, Stephen "Pat" | Aerospace Consultant |
| Gardner, Ruth | Kennedy Space Center |
| Holloway, Tommy | Aerospace Consultant |
| Levin, Lon | SkySevenVentures |
| McDaniel, Mark | McDaniel & McDaniel Attorneys, LLC |
| Sieck, Robert *(via telecon)* | Aerospace Consultant |
| Voss, James | University of Colorado, Boulder |
| *Science Committee Members:* | |
| Wadhwa, Meenakshi, *Interim Chair* | ASU |
| Denning, Elaine, *Executive Secretary* | NASA Headquarters |
| Avery, Susan | Woods Hole Oceanographic Institution |
| Cerf, Vinton | Google |
| Desai, Mihir | SWRI |
| Jernigan, Tammy | LLNL |
| Larson, Michelle | Adler Planetarium |
| Patterson, Pat | Space Dynamics Laboratory |
| Scowen, Paul, *designee* | ASU |
| Secada, Walter | U of Miami |
| Verbiscer, Anne | UVA |
| Weiser, Marc | RPM Ventures |
| *NASA Attendees:* | |
| Andrews, Daniel | NASA ARC |
| Bailey, Brad | NASA ARC |
| BajPayee, Jaya | NASA ARC |
| Bicay, Michael | NASA ARC |
| Clarke, Steven | NASA HQ |
| Colaprete, Anthony | NASA ARC |
| Crusan, Jason | NASA HQ |
| Favors, Jamie | NASA HQ |
| Gates, Michelle | NASA HQ |
| Gerstenmaier, William | NASA HQ |
| Guidi, John | NASA HEO AES |
| Guzman, Alberto | NASA ARC |

| | |
|---|---|
| Hill, Bill | NASA HEO/ESD |
| Karcz, John | NASA HQ and ARC |
| Kennedy, Eracenia | NASA HQ |
| Korsmeyer, David | NASA ARC |
| Lueders, Kathryn | NASA CCP |
| Melton, Forrest | NASA ARC |
| Noble, Sarah | NASA HQ *(via telecon)* |
| Scimemi, Sam | NASA HEO ISS |
| Sun, Sid | NASA ARC |
| Trimble, Jay | NASA ARC |
| Vaughan, Ryan | NASA |
| Zuniga, Allison | NASA ARC |
| Zurbuchen, Thomas | NASA HQ |

*Other Attendees:*

| | |
|---|---|
| Boyle, Angela | KBR Wyle |
| Burns, Jack | U Colorado |
| Deepal, Ravi | Science & Technology Corp. |
| Gibbs, Kristina | KBR Wyle |
| Hale, Wayne | NASA Advisory Council |
| Lyles, Lester | NASA Advisory Council |
| Neff, Jon | The Aerospace Corporation |
| Sanders, Patricia | NASA ASAP |
| Tador, Al | SSL |
| | |
| Zellner, Nicolle | Albion College |
| Zimmerman, Robert | Symbiotek |

*Telecon Attendees:*

| | |
|---|---|
| Alison Sheridan | Boeing |
| Alison Zuniga | NASA Ames Research Center |
| Amanda Moore | NASA |
| Andrea Riley | NASA HQ |
| Ann Zilkeski | Lockheed Martin |
| Ashley Edwards | NASA HQ |
| Ben Kallen | Lewis-Burke Associates |
| Bill Harwood | CBS News |
| Bill Peterson | n/a |
| Bob Doley | The Boeing Company |
| Brad Bailey | NASA Ames |
| Bradley Carpenter | NASA |
| Bryan Sims | NASA Office of CFO |
| Carlyle Webb | NASA |
| Carol Galicka | NASA |
| Carrie Arnold | Boeing Communications |

| | |
|---|---|
| Chris Gilbert | VE Consult |
| Chris Lam | SpaceX |
| Chris Moore | NASA HQ |
| Christine Pham | NASA Ames Research Center |
| Craig Kundrot | NASA HQ |
| Dan Lester | Exenitcs |
| Danielle Richey | Lockheed Martin |
| Danny Lentz | n/a |
| David Millman | n/a |
| Deann Reilly | The Boeing Company |
| Denise Varga | NASA HQ |
| Desirae Seward | NASA HQ |
| Dev Chang | NY Times |
| Diana Ly | NASA |
| Dimetrius Hanaloft | Morris Inc. |
| Elizabeth Taylor | NASA |
| Ellen Grant | NASA |
| Elsie Weigel | NASA |
| Eric Berger | Ars Technica |
| Erika Vick | NASA |
| Erin Mahoney | NASA HQ |
| Frances Donovan | NASA Space Biology Project |
| Gail Allen | ASGSR |
| Garry Burdick | NASA JPL |
| Gene Mikulka | Talking Space |
| Greg Mann | NASA |
| James Green | NASA HQ |
| Jeff Foust | Space News |
| Jennifer Read | NASA JSC |
| Jeremy Hall | n/a |
| Jerry Posey | Lockheed Martin |
| John Kross | Ad Astro Magazine |
| John Rumps | n/a |
| Josh Barrett | Boeing |
| Julie Robinson | NASA |
| Katelyn Kuhl | NASA |
| Kathryn Hambleton | NASA |
| Kathy Laurini | NASA |
| Keith Cowing | NASAWatch.com |
| Kelly O'Rourke | NASA HQ HEO Mission Directors |
| Kent Bress | NASA HQ |
| Kevin Metrocavage | NASA HQ |
| Kiersten White | NASA HEO Human Exploration Operations |
| Kristina Gibbs | KBR Wiley NASA Ames Survey Project |

| | |
|---|---|
| LaDonna Miller | NASA JSC |
| Linda Karanian | Karanian Aerospace Consulting |
| Linda Timucin | NASA |
| Loren Grush | The Verge |
| Marchel Holle | Space Foundation |
| Marcia Smith | spacepolicyonline.com |
| Margaret Race | SETI Institute |
| Margaret Roberts | NASA HQ |
| Margarite Broadwell | NASA |
| Mark Mozena | ULA |
| Marshall Smith | NASA |
| Martin Burkey | Marshall Space Flight Center SLC Program |
| Martin Frederick | Northrop Grumman |
| Mary Faller | NASA |
| Mary Jones | Vision Analytics |
| MaryAnn Cevalier | NASA |
| Michael Barrett | NASA Glenn Research Center |
| Michael Veil | n/a |
| Mike Curie | NASA |
| Mike Henry | American Institute of Physics |
| Nevin Brittain | Space Day |
| Nicholas White | USRA |
| Nicole Herrman | NASA HQ |
| Nujoud Merancy | NASA JSC |
| Patricia Soloveichik | Boeing |
| Philip Sloss | NASAspaceflight.com |
| Rick Irving | NASA |
| Rick Loft | Aerospace Industry |
| Robert Sieck | Panel Member |
| Robyn Gatens | NASA HQ |
| Ronald Freeman | American Institute of Aeronautics & Astronautics |
| Shandy McMillian | NASA HQ |
| Stefanie Payne | NASA HQ |
| Stephanie Getty | NASA Goddard |
| Stephen Clark | Space Flight Now |
| Steve Aloezos | NASA HQ |
| Steve Davidson | NASA |
| Steven Eisenman | NASA JPL |
| Steven Ramm | Lockheed Martin |
| Steven Seisloff | Boeing |
| Sue Leibert | NASA HQ |
| Tim Fernholz | Reporter with Quartz |
| Tom Whitmeyer | NASA |
| Toni Mumford | NASA HQ |

| | |
|---|---|
| Tony Antonelli | Lockheed Martin |
| Tremayne Days | NASA JSC ISS Program Office |
| Wayne Jermstead | NASA |
| William Pratt | Lockheed Martin |
| Zachary Pirtle | NASA |

**Human Exploration and Operations Committee**
**NASA Ames Research Center**
**NASA Ames Conference Center**
**Moffett Field, CA**
**August 27-28, 2018**

## LIST OF PRESENTATION MATERIAL[1]

1) Human Exploration and Operations Overview [Gerstenmaier]
2) ISS Space Station Status [Scimemi]
3) Exploration Systems Development Update [Hill]
4) Commercial Crew Program Status [Lueders]
5) Status of Power and Propulsion Element (PPE) for Gateway [Gates]
6) SMD Cislunar Activities Overview [Zurbuchen/Clarke]
7) Cislunar and Gateway Overview [Gerstenmaier]
8) Gateway Science Summary [Guidi]
9) Community-Driven Priorities for Lunar Landed Science [Noble]
10) Rethinking Solar System Bombardment: New Views on the Timing & Delivery of Lunar Impactors [Zellner]
11) Transformative Science from the Moon: Astrophysics, Cosmology, and Heliophysics [Burns]

[1] Available at: https://www.nasa.gov/directorates/heo/nac-heoc