National Aeronautics and Space Administration
Washington, DC

NASA ADVISORY COUNCIL

Human Exploration and Operations Committee

July 24-25, 2017

Langley Research Center
National Institute of Aerospace
Hampton, VA

MEETING MINUTES

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Kenneth Bowersox, Chair

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Bette Siegel, Executive Secretary

Human Exploration and Operations Committee Meeting
Langley Research Center
National Institute of Aerospace
Hampton, VA
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Monday, July 24, 2017

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 10:45 a.m. Dr. Siegel apologized for a delay in beginning the meeting attributable to a technical communication problem. She announced that it was a Federal Advisory Committee Act (FACA) meeting and therefore, would be open to the public. Minutes would be taken and posted online, along with the presentations. Dr. Siegel explained that there would be an opportunity for the public to make comments toward 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. He introduced Gen. Lester Lyles, Chair of the NAC, and Dr. Patricia Sanders, Chair of the NASA Aerospace Safety Advisory Panel (ASAP).

Human Exploration and Operations Mission Directorate

Mr. Bowersox introduced Mr. Greg Williams, Deputy Associate Administrator (AA) for Policy and Plans in NASA's Human Exploration and Operations Mission Directorate (HEOMD). Mr. Williams briefed the Committee on events in the HEOMD. He reported on recent accomplishments in network operations and development in the Space Communications and Navigation (SCaN) Division. He described work performed in technology development and demonstration, spectrum management, policy and strategic communications, and data standards. He reviewed progress on the Tracking and Data Relay Satellite-M and the Deep Space Network Aperture Enhancement Project (DAEP). He provided an update on progress made in the Human Spaceflight Capabilities Division. He presented a chart on International Space Station (ISS) accomplishments.

Mr. Williams reviewed recent accomplishments made by SpaceX and Boeing in the Commercial Crew Program (CCP). He reviewed the status at the GeneLab and noted that it now hosts 116 data sets that are available worldwide. Mr. Williams discussed recent accomplishments in Physical Sciences. He presented a chart on the Physical Sciences Informatics (PSI) status. He described the open science construct. In response to a question from Mr. Bowersox, Mr. Williams explained that the Primary Investigator (PI) is afforded a period of time in which the data is embargoed. Dr. Siegel noted that the time is generally one year. The Cool Flames Investigation (CFI) was

described. It is an outgrowth from the Flame Extinguishment Experiment (FLEX). Mr. Williams noted that the low-temperature flames responsible for cool-flame droplet burning are extremely important in developing new engines. He described recent accomplishments in Space Biology and in the Exploration Systems Division (ESD). He discussed work performed on the liquid hydrogen tank structural qualification test article at NASA's Michoud Assembly Facility and on the Mobile Launcher (ML). He described Orion exit procedure testing performed by a NASA and Department of Defense (DoD) team off the coast of Galveston, Texas.

Mr. Williams reviewed FY 2017 accomplishments by the Launch Services Program. The Program has provided end-to-end launch services management and support to over 40 missions in various stages of development.

Mr. Williams discussed work done on spacecraft fire safety by Advanced Exploration Systems (AES). He described the Saffire-III fire safety experiment and noted that Saffire IV through VI would demonstrate combustion products monitoring and post-fire cleanup technologies. He described the Korea Pathfinder Lunar Orbiter (KPLO) and the instruments that it will carry. One instrument will be the AES-sponsored "ShadowCam" from Arizona State University and Malin Space Science Systems to image the Moon's Permanently Shadowed Regions (PSR). It has over 800 times the sensitivity of the Lunar Recognizance Orbiter (LRO) Narrow Angle Camera. Mr. Williams discussed AES developments in lander technology, in-space manufacturing, and radiation sensing. He described how the Additive Manufacturing Facility on ISS was used to print radiation shielding.

Mr. Bowersox thanked Mr. Williams for his presentation and noted that Mr. Williams would be providing a presentation at the joint meeting with the Science Committee and HEO committee.

International Space Station Update and Accomplishments

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 upcoming flight plan and described the Increment 52 crew. He presented charts showing the work performed on Increments 51 and 52 and how crew time was utilized on those increments. He reviewed ISS research statistics. More than 1400 papers on ISS scientific results have been published to date. A chart illustrating Increment 49/50 crew time spent on scientific investigations, by sponsor, was presented. Mr. Scimemi noted that actual time significantly exceeded planned hours. He explained that the methodology used to perform science on the ISS has been optimized. In addition, the crew has been much more efficient in moving cargo off and on the ISS, which has made more crew time available for science.

Mr. Scimemi explained that benefits from the ISS have been increased through international collaboration. He presented a chart listing those benefits. He discussed the upcoming extra-vehicular activity (EVA) plan and described recently completed EVAs. Mr. Scimemi reviewed a chart on total consumables on board the ISS. He discussed the External Active Thermal Control System (EATCS) ammonia leak. The leak decreased after recent venting and will continue to be monitored. Mr. Bowersox noted that ISS crews become more efficient the longer they remain on the ISS. Crews on the ISS perform approximately 42 hours of science per week and look forward to working on science. Mr. Scimemi stated that ISS crews are now trained to be generalists. He added

that the Environmental Control and Life Support System (ECLSS) has become more stable and requires less crew time for its maintenance.

Mr. Scimemi discussed the Orbital ATK (OA)-7, the SpaceX-10, and the SpaceX-11 mission successes. He reviewed the mission status for SpaceX-12, OA-8, and Commercial Resupply Services (CRS)-2.

Mr. Scimemi presented a graphic showing the phases for the Expanding Human Presence Partnership program. Phase 0 is for continued research and testing on the ISS to solve exploration challenges. It will be used to develop and demonstrate long-term, deep-space life-support systems and technologies. These include rendezvous sensors, a docking system, and habitation structures. Mr. Bowersox observed that if the ISS is terminated in 2024, there would be insufficient time to test the ECLSS intended for the Mars Mission.

Mr. Scimemi explained that missions in cislunar space will begin in Phase 1. During this phase, the Deep Space Gateway (DSG) will be built and the Deep Space Transport (DST) will be initiated. In Phase 2, the assembly of the DST will be completed and a year-long Mars simulation mission will be conducted. In Phases 3 and 4, crews will begin expeditions to the Martian system and the surface of Mars. Mr. Scimemi presented a chart showing the long-duration, Deep Space ECLSS Roadmap.

Mr. Scimemi presented a graphic showing the Neutron Star Interior Composition Explorer (NICER) instrument that will study the physics of neutron stars. He described the Station Explorer for X-ray Timing and Navigation Technology (SEXTANT) instrument that will use 56 telescopes to detect x-ray photons from pulsar beams of light to estimate their arrival times. Those measurements will be used to develop algorithms for a celestial Global Positioning System (GPS) for the cosmos. Mr. Scimemi described the ISS Research and Development (R & D) conference recently held in Washington, DC. There were over 1000 participants. Next year's session will be held in San Francisco in July. An ISS Stakeholder Workshop will be held in August in Washington, DC. The workshop will address issues and policies related to the future of the ISS. Those issues include the U.S. presence in low-Earth orbit (LEO) and LEO commercialization.

Mr. Bowersox thanked Mr. Scimemi for his presentation.

Exploration Systems Division

Mr. Bowersox introduced Mr. Wayne Jermstad, Deputy Chief Engineer and Deputy Director, Cross-Program Systems Integration (CSI), ESD. He briefed the Committee on recent developments in the Division. Mr. Jermstad described recent major CSI technical performance accomplishments. The Exploration Mission (EM)-1 Integration Review has been completed. CSI has baselined 1,065 Operations and Maintenance Requirements and Specifications (OMRS) records; 1,241 remain to be baselined. Ninety-one Launch Commit Criteria (LCC) have been baselined; 43 LCCs are under review, and 368 remain to be baselined. An independent Crew Egress Exercise Neutral Buoyancy Lab session and Open Water Testing with the United States Coast Guard has been completed.

Mr. Jermstad reviewed Cross-Program Integration Team (CPIT) top technical issues. They are: Ground Systems Development and Operations (GSDO) flight applications software the Interim Cryogenic Propulsion Stage (ICPS) umbilical loads, the Orion and Space Launch (SLS) inconsistent constraints on wind exposure while on the pad, and the communication up-link for the EM-2 Exploration Upper Stage (EUS). He discussed a new medical requirement to limit the amount of "crew time on back" (CTOB) to 2 hours 45 minutes. He noted the potential need for smaller thrusters on the EUS for fine attitude hold for Orion docking. He described deficiencies in the Launch Control System architecture that require upgrading services and software to process the expected amount of data from the vehicle and ground support equipment. In response to a question from Mr. Joseph Cuzzupoli, Mr. Jermstad stated that there are four major and several minor software packages for the stack. In response to a question regarding CTOB, Mr. Jermstad explained that the engineers are looking at how to improve seat comfort and whether it would be possible to use looser straps that could be tightened by the crew members themselves. In response to a question from Mr. Cuzzupoli, Mr. Jermstad explained that there are eight umbilicals for the SLS that must be released simultaneously.

Mr. Jermstad presented graphics on the Umbilical Release. He described multiple failures in its development and the remedies that have been developed to address those failures. He discussed ML modal testing. He described how a vehicle's bending mode becomes entangled with the characteristics of the ML once they are coupled together. Mr. Jermstad discussed major CSIT independent assessments that are in progress. He noted that the Flight Safety Office (FSO) is assessing the 186 "*Significant Incidents and Close Calls in Human Spaceflight"* for relevance and applicability to ESD.

Mr. Bowersox thanked Mr. Jermstad for his presentation.

Commercial Crew Program

Mr. Bowersox introduced Mr. Steve Stich, Deputy Manager, CCP, who briefed the Committee on the Program's progress. He reviewed mission planning and preparations for eight planned CCP missions. Boeing's uncrewed orbital flight test is scheduled for June 2018, and its first crewed flight test is scheduled for August 2018. SpaceX' S Demo Mission 1 flight to the ISS without crew is scheduled for February 2018. Its first flight to ISS with crew, Demo Mission 2, is scheduled for June 2018. Recovery trainers for both providers have been delivered and rescue training preparations are underway. Mr. Stich presented a combined milestone summary chart for the Commercial Crew Transport Capabilities (CCtCap) Contracts. He described the CCP top programmatic risks: DoD search and rescue posture, inability to meet loss of crew (LOC) criteria, ammonia emergency response, and DoD search and rescue training schedule. He also described the CCP top program safety risks. They are: inability to meet LOC, aborting into sea states with unsafe rescue, spaceflight associated neuro-ocular syndrome (SANS) exacerbations, and the ammonia emergency response. In response to a question from Mr. Bowersox, Mr. Stich explained that proprietary risks specific to each provider are maintained in a separate database that is Sensitive But Unclassified (SBU). Those risks are tracked in each provider's own system and cross-checked by NASA. Mr. Stich discussed training on search and rescue.

Mr. Stich reviewed a chart on Boeing's completed milestones and described Boeing's accomplishments in hardware and software testing, launch pad and crew training, production and qualification, and structural test article. He described Boeing's Crew Flight Test (CFT) thruster testing underway at the NASA White Sands Test Facility (WSTF). Mr. Stich reviewed a chart on SpaceX's completed milestones and described its accomplishments in hardware and software testing, and launch pad and crew training. He noted that Space X completed eight launches in the last six months. He discussed SpaceX's accomplishments in hardware production and qualification. There are four Dragon Modules in production. SpaceX has completed the first pressurized spacesuit test utilizing NASA crew. In response to a question from Mr. Cuzzupoli, Mr. Stich stated that the chemistry between the NASA team and the providers' teams is good. He explained that the providers are responsible for the countdowns and the flight operation, that they have reached a level of maturity, and that they recognize each other's strengths. He added that he is very encouraged going forward.

Mr. Bowersox thanked Mr. Stich for his presentation.

Discussion and Recommendations

Mr. Bowersox explained that the Committee's findings and recommendations must be approved by the NAC and that Committee conclusions and observations do not require NAC approval. Dr. Siegel noted that findings and recommendations are the two types of NAC "formal advice" to NASA. She described how they differ. Mr. Bowersox noted that Gen. Lyles had requested a finding from the Committee on plans for ISS beyond 2024.

Mr. Bowersox reviewed the Committee concerns and observations from its last meeting. Mr. Wayne Hale observed that the concerns do not receive much attention. Mr. Bowersox concurred and noted that the advantage to using concerns is that they are not subject to modification by the NAC. After further discussion, the Committee settled upon the following concerns and observations:

Concerns

- Budget uncertainty and lack of flexibility in use of funds continues, and now has greater potential for program disruption as SLS and Orion get closer to launch.

- The Deep Space Gateway could be capable of other deep space missions, in addition to its prime mission as a node for development and staging of the Deep Space Transport. The committee is concerned that requirements for the Gateway may grow excessively during the development phase, and encourages the HEO team to maintain focus on the prime mission when developing the Gateway's system requirements.

- Bureaucratic processes that NASA imposes on itself do not always add value to balance their load on the organization and are a threat to accomplishment of NASA's exploration

mission.

- The number and intensity of current reviews of the HEO programs are not helpful and use too many precious resources.

- 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

Observations

- The committee observed that a great deal of technical progress has been made on HEO programs since our last meeting, and continues to be impressed by the amount of work being managed by the directorate team.

- NASA has a lot of work ahead to accomplish the goals being set out for deep space exploration, while at the same time developing commercial crew capabilities and managing the International Space Station. Increased emphasis on organizational efficiency, stable requirements and decision velocity will be critical to meet the current schedules.

Mr. Bowersox discussed potential special topics for the Committee to consider in the future.

The Committee considered a proposed finding on the timing for ISS decommissioning. The discussion covered operational inefficiency during preparations for decommissioning, uncertainty for science and investors, and whether an early decision should be made on extending the ISS to 2024. Dr. Sanders explained that it could be difficult for a decision to be made before a new Administrator is appointed to the Agency. Mr. Hale commented that the longer the ISS is continued, the longer those funds are not available for exploration. Mr. Bowersox explained that the longer the ISS is in orbit, the less likely it would be for commercial space to launch its own space station. He added that exploration is what makes it useful to extend the ISS past 2020. Dr. Sanders cautioned that there is no guarantee that financial resources from the ISS would remain with NASA if the ISS were decommissioned. She also noted that a three-year validation on the ECLSS could not be accomplished by 2024. Mr. Bowersox suggested that setting criteria for decommissioning would be better than setting a firm date.

Mr. Bill Hill expressed unease over how lean the industrial contractor base had become, particularly in avionics. Dr. Sanders reported that NASA leadership is concerned over decision velocity. The dissenting opinion process slows things down. She suggested that it may be necessary to assume additional risk. While dissenting opinions are important, it is also important

to make decisions. Mr. Hale commented that it would be nice for the Committee to hear from program managers. Dr. Sanders stated that it would also be good to hear from the Agency's chief engineers.

Dr. Siegel adjourned the committee meeting for the day at 5:15 p.m.

Tuesday, July 25, 2017

NAC HEO COMMITTEE / SCIENCE COMMITTEE PUBLIC MEETING

Opening Remarks for Joint Session

Dr. Siegel convened the joint meeting of the HEO Committee and the Science Committee (SC) at 9:00 a.m. She introduced Mr. Bowersox, Ms. Elaine Denning, SC Executive Secretary, and Dr. Bradley Peterson, SC Chair.

Ms. Denning called the meeting to order. She announced that it was a Federal Advisory Committee Act (FACA) meeting and, therefore, would be open to the public. Minutes would be taken and posted online, along with the presentations. She explained that there would be an opportunity for the public to make comments toward the end of the meeting, and she requested that all questions and comments be held until that time.

Ms. Denning introduced Dr. Peterson, who asked the members present from each committee to introduce themselves. Following those introductions, Mr. Bowersox explained that he and Dr. Peterson had decided to have a joint committee meeting on deep space telescopes. Dr. Peterson thanked the members from each committee for their willingness to spend an entire day learning about deep space telescopes and for exploring areas of cooperation.

Human Exploration and Operations and Science Emerging Opportunities

Human Exploration and Operations Future Exploration Plans

Mr. Ken Bowersox re-introduced Mr. Williams, who discussed human exploration plans. He explained that the Nation' s goal in space exploration is to expand human presence deeper into the solar system and that NASA's role is to lead the effort. He reviewed the goals and objectives in Section 202 of the NASA Transition Authorization Act of 2017. He presented a chart on the strategic principles for sustainable exploration:

- fiscal realism,
- scientific exploration,
- technology pull and push,
- gradual build-up of capability,
- economic opportunity,
- architecture openness and resilience,

- global collaboration and leadership, and
- continuity of human spaceflight.

Mr. Williams presented charts on the phases for expanding human presence. Phase 0 is for the ISS to serve as a platform for deep space exploration, scientific research, economic growth, and global diplomacy. Phase 1 will be used to establish deep-space leadership and prepare for DST development. Phase 1 plans anticipate six EM SLS flights.

Dr. Michele Gates was invited by Mr. Greg Williams to discuss the advantages of solar electric propulsion (SEP) in cislunar space. She explained that SEP is scalable to higher power systems for deep space human exploration. It will have a 5- to 15-fold savings in propellant compared to chemical-only systems with equivalent trip times. NASA's plan is to start development on the DSG when crews fly to the vicinity of the moon. A power propulsion element (PPE) would be the first element in a cislunar DSG. The PPE would leverage advanced SEP bus formulation progress from the Asteroid Redirect Mission (ARM). She described progress on solar array development and upcoming events on electric propulsion development.

Mr. Williams explained that Phases 2 and 3 would be used to complete the DST and conduct simulation missions. In response to a question from Mr. Bowersox, Mr. Williams stated that the cislunar orbit could be as high as 70,000 miles from the Moon's surface. The DST would be capable of moving around the Moon's vicinity and go from high-lunar orbit to high-Earth orbit and to different Lagrange points.

Mr. Williams explained that HEOMD is directing the maturation of the DSG concept to ensure that it enables evolution to the DST and is part of Mars mission plans. He described the HEOMD Standards Working Group. He discussed interface and interoperability standards and design specifications for natural environments. He presented charts on HEOMD and SMD joint activity areas. These include the Mars Exploration Program (MEP), science instruments on the ISS, potential collaboration on satellite and telescope servicing, studying space weather and the effect of space radiation on astronauts, and deep space optical communications (DSOC). Other joint activity areas are the Frontier Development Lab (FDL), a 2018 workshop on science in cislunar space, and the KPLO.

Mr. Williams invited questions from the two committees. Dr. Tamara Jernigan asked him to comment on the most compelling technical challenges. His response was entry, descent, and landing (EDL) and radiation protection. Dr. Mark Robinson asked for the mass and dimensions for the habitation module. Mr. Bowersox explained that the DSG would be about the size of an ISS module.

Dr. Peterson thanked Mr. Williams for his presentation.

Science Opportunities

Science Opportunities Overview

Dr. Peterson introduced Dr. Thomas Zurbuchen, AA, Science Mission Directorate (SMD). Dr. Zurbuchen discussed the nexus between SMD and HEOMD. Dr. Zurbuchen explained that SMD has

a high impact, integrated, and multi-faceted portfolio. SMD has four divisions: Heliophysics, Earth Science, Planetary Science, and Astrophysics. Total counts were presented on spacecraft, CubeSats, balloon payloads, sounding rocket flights, Earth-based investigations, technology development, and research. A graphic was presented showing the operating and future science fleet. SMD has three key science themes. The first is discovering the secrets of the universe; the James Webb Space Telescope (JWST) will help unlock those secrets. The second theme is searching for life elsewhere. A graphic was presented showing new Kepler planet candidates. To date, 4,034 exoplanet canidates have been identified. The third theme is safeguarding and improving life on Earth; for example, the Cyclone Global Navigation Satellite System (CYGNSS) measures the strength of hurricanes. The Geostationary Operational Environmental Satellite (GOES)-16 maps lightning strikes. CubeSats provide a relatively inexpensive learning and training opportunity for young scientists.

Dr. Zurbuchen described SMD's combined effort across topical areas. He explained that SMD science disciplines interrelate to HEOMD with many synergies. Examples are the LRO, the MEP, studying space weather, the effect of space radiation on astronauts, collaboration on launch services, ScaN, and planetary protection. He described the MEP and the Mars Rover 2020, which will conduct science, monitor Mars' atmospheric conditions and help address strategic knowledge gaps. He explained that the highest priority objective identified in the most recent Planetary Science Decadal Survey is to bring a Mars sample to Earth.

Dr. Zurbuchen discussed future science opportunities. He explained how they will identify science opportunities in HEOMD's developing architecture, including the DSG infrastructure. He described science instruments aboard the ISS. One instrument, the Neutron star Interior Composition Explorer (NICER), is revealing the structure, dynamics, and energetics of neutron stars. He described how the SLS enables future exploration and enhances science's access to the outer solar system because it makes a direct interplanetary trajectory possible.

Dr. Zurbuchen concluded his presentation by describing the Hubble Space Telescope (HST) servicing missions. Dr. Kathyrn Flanagan noted that large aperture telescopes are preferable, but posited that it would be very difficult to assemble these in space. Dr. Zurbuchen responded that the National Academies Decadal Survey made clear the importance of building larger space telescopes. Learning how to do that, he explained, is critical. It is important to think about technology development in ways that would not require too many "big leaps." It is important to go forward "without betting the farm." He opined that a more tempered approach is better and smarter. Dr. Robinson stated that there are many possibilities. For instance, small spacecraft could be built to deliver samples to the Gateway, and people could rendezvous with the Gateway and bring the samples to Earth. It is a hypothesis that needs testing.

Dr. Peterson thanked Dr. Zurbuchen for his presentation.

Future Telescopes Human Servicing

Dr. Peterson introduced Dr. Jeffrey Hoffman, Massachusetts Institute of Technology, NASA Astronaut (ret.). Dr. Hoffman noted that before he became an astronaut, he was an astrophysicist. For him, one of the joys of the HST was bringing together the two worlds of astrophysics and

human spaceflight. He described how astronauts had been flown to the Hubble on the Space Shuttle multiple times to perform repairs and install new instruments. Those repairs and instruments have enabled new discoveries, including proof of black holes, supernova 1As, evidence that we live in an accelerating universe, confirmation of the dark energy principal, direct mapping of dark matter, the first detection of an organic molecule in the atmosphere of a Jupiter - like planet in the Milky Way Galaxy, and 500 extremely old proto-galaxies formed just after the Big Bang.

Dr. Hoffman presented a chart on the contributions of the ten most productive NASA programs as estimated by the *Science News* Annual Discoveries list. He explained that the HST made far more contributions than any other program. It reflects the effectiveness of regular servicing by astronauts and collaborative work with the science community. Servicing by the Shuttle re-invented the telescope at each visit. The complexity of what the crew accomplished increased with each mission. The HST continues to make remarkable scientific discoveries powered by new instruments taking advantage of current technology.

Dr. Hoffman explained that some HST modules had been designed for EVA servicing and some had not. Both kinds have failed and needed servicing. There is a difference between an instrument being designed for servicing and unplanned servicing. He appreciates the use of robots in space; however, they are not as adaptable as humans. The HST is the most productive instrument NASA has ever had. Given the HST's design, robotic servicing risks were too great. Dr. Hoffman explained that the configuration control on the HST was superb and that is the reason servicing was so successful. HST demonstrated the value of servicing. Servicing was not used on the other great observatories. Chandler was not designed for servicing and was not in a Shuttle-compatible orbit. It is, however, still doing great science.

Dr. Hoffman described the Robonaut. It is on the Space Station and is underutilized; he believes that it may be broken. The Robonaut's hand is designed to resemble a human hand.

Dr. Hoffman explained that the more complex a system is, the more likely it is for something to go wrong. Instruments should be designed for servicing from the start and allow for new technology. Designs should make servicing tasks robot-compatible. Control and document configuration are very important. He described the JWST and stated that it would have state-of-the-art detectors. He noted that scientists are already looking ahead to bigger and better telescopes.

Dr. Robinson asked whether any servicing had been performed on the ISS robotically. Dr. Hoffman responded that the Canadian Robotic Arm has been used for external repairs and for transferring cargo. He noted that robotic operations tend to be slower than humans; however, because robots don't run out of oxygen and can be controlled from the ground, it isn't a problem.

Dr. Peterson thanked Dr. Hoffman for his presentation.

Future Assembly and Servicing Study Team

Dr. Peterson introduced Dr. Ronald Polidan, Polidan Science Systems & Technologies, LLC. Dr. Polidan briefed the committees on the Future Assembly/Servicing Study Team (FASST). It is a

community-based assessment of future astronaut and robotic capabilities to achieve major scientific goals in space astrophysics. A chart was reviewed on the FASST core and affiliated members. Dr. Polidan described future challenges. Science in the future will require larger telescopes for which no existing launch vehicles will enable autonomous deployment. Flagship observatories can return spectacular science for their entire lifetime. There is a need to develop capabilities to upgrade and service them over 50 to 100 years. For example, HST is entering its 28th year of operation and is still providing an exceptional science return.

Telescopes may occasionally need repairs during their planned primary mission, as was the case with the HST. Autonomously deployed, post-JWST large space telescopes are being designed to specifically use the payload capabilities of the SLS Block II. There is no back-up if the SLS becomes unavailable or suffers a failure. The solution is to develop the capabilities and technologies to service and assemble future generations of large space telescopes in space. In response to a question from Dr. Zurbuchen, Dr. Polidan explained that mirror segments can be stowed in a support structure in the fairing and then assembled in space, greatly reducing launch loads on the mirrors with respect to that of a fully assembled launch and deployment. He agreed that cost-effective ways to do that need to be developed.

Dr. Polidan stated that SMD missions that use Exploration infrastructure as "pull technology" should have 2020 Decadal Survey endorsement, which would require much-improved engineering designs and trade studies of space assembly over the next two years. There is a need to begin creating a technology roadmap and implementing early development efforts. One example would be to use the ISS as a testbed prior to its termination. He noted that having an assembly/servicing capability using medium-lift vehicles and a DSG-like facility may offer an option to the 2020 Survey if the SLS heavy-lift is unavailable.

Dr. Polidan described disruptive technologies or capabilities that may be developed and either demonstrated or sufficiently matured for flight infusion during the 2020s. These include industry-provided, low-cost launch vehicles with frequent launch windows and in-space, robotic technologies for servicing and assembly by industry and government. He reviewed a chart on the FASST Terms of Reference and discussed FASST planned activities. Dr. Polidan described the Community Technical Interchange Meeting (TIM) on future priorities in astrophysics enabled by in-space servicing and assembly. The TIM organizing team consists of a representative from each "decadal survey" study: NASA SMD and Space Technology Mission Directorate (STMD), the industry "Gateway" studies, DoD, and other experienced industry leaders. TIM products and deliverables were described.

Dr. Peterson thanked Dr. Polidan for his presentation.

Science Enabled by Human Exploration

Dr. Peterson introduced Dr. Ben Bussey, Chief Exploration Scientist, HEOMD. He briefed the committees on an upcoming workshop that will be conducted on the topic of science in cislunar space. The workshop will be a forum to articulate science enabled by near-term, human space exploration. Dr. Bussey asserted that science and research are essential elements of Human

Exploration. He stated that early integration of science and research goals and objectives into human exploration architectures is important.

Dr. Bussey described a recent International Space Exploration Coordination Group (ISECG) Science White Paper (SWP). The SWP discusses the international view of the science enabled by human exploration after ISS. The ISECG agencies acknowledge that science communities are major stakeholders and that scientific knowledge gains are an important benefit of, and justification for, human exploration activities. Dr. Jernigan commented that the astrophysics community is concerned that piggybacking on human space opportunities could undercut their own science programs. Dr. Bussey explained that it should be portrayed not as a threat, but as an additional opportunity due to the human spaceflight program. Dr. Alan Boss asked whether the return vehicle, after delivering crew to the DSG, could go to Lagrange Point 2 (L2) to deploy or service a science instrument. Dr. Bussey responded that space tugs could be used to maneuver instruments and that it is essentially an engineering issue. He added that he was giving his presentation "now" because this is when the DSG is being designed.

Dr. Bussey asserted that human exploration permits the emplacement of scientific instruments on a scale different from the scale typically considered by scientists and engineers. That is because there are fewer constraints imposed by mass, power, and volume. He discussed the DSG science study, which will determine in detail the high-quality science that can be conducted from the DSG and the level of resources that would be required. The anticipated resources needed are mass, power, volume, data, crew-time, and location or preferred orbits. A chart describing the workshop steering committee was presented. The workshop is jointly sponsored by SMD and HEOMD, and co-convened by NASA Headquarters (HQ), NASA Johnson Space Center (JSC), NASA Marshall Space Flight Center (MSFC), and NASA Goddard Space Flight Center (GSFC). Attendance will be by invitation only and based on an open call for presentations.

Dr. Peterson thanked Dr. Bussey for his presentation

Discussion on Findings and Recommendations

The committees briefly discussed potential findings and recommendations.

Space Radiation

Dr. Peterson introduced Dr. Lisa Simonsen, General Engineer, NASA Langley Research Center (LaRC) and Dr. Cary Zeitlin, NASA Johnson Space Center, who briefed the committees on the Mars radiation environment. Dr. Simonsen distinguished space radiation environmental considerations in ISS LEO, in deep space, and on the Mars surface. In LEO, the magnetosphere provides protection from solar particle events (SPE) and low energy galactic cosmic radiation (GCR). The total dose rate in LEO is similar to the Mars surface. In deep space, there is no protection from SPE or GCR, and the dose rate would be approximately three times the ISS. Dr. Simonsen explained that space radiation produces potential increased health risks that include cancer, cardiovascular disease, central neural system (CNS) effects, and acute radiation syndromes. It is important to understand individual radiation sensitivity. SMD and HEOMD measurements that accurately characterize the

space radiation environment are needed to optimize mitigation strategies. Dr. Simonsen discussed the significance of environmental data and explained that it would help validate biological countermeasures.

Dr. Zeitlin described the Mars Science Lab (MSL) Radiation Assessment Detector (RAD). It is a joint SMD-HEOMD project that continues to operate successfully on Mars since touchdown on August 6, 2012. It is characterizing the changing GCR and SPE radiation environment on Mars over the solar cycle. Dr. Zeitlin reviewed a chart on dose rates incurred on the cruise to Mars and reviewed the first surface observations. The dose rate dropped on the surface by a factor of 2.5, whereas a factor of 2 would be expected on an airless body. Dr. Zeitlin described how radiation shielding was provided by local terrain while Curiosity was parked near a cliff. The MSL-RAD represents the first opportunity to measure exposure to high-energy neutrons, which potentially contribute to overall radiation exposure. Mr. Bowersox asked whether different material compounds could help provide shielding. Dr. Simonsen responded that different material compounds would be more useful in protecting electronics. Dr. Zeitlin described a MSL-RAD workshop that had been conducted in June 2016. The workshop results will be reported in a special issue of *Life Sciences in Space Research.* Charts were presented on the Alpha Magnetic Spectrometer (AMS)-02 and the data it has generated.

Dr. Simonsen described the radiation doses expected on current and future human space missions. She reviewed a chart on NASA crew mission doses, and she discussed different ways to approach protection and mitigation. She described efforts to optimize radiation protection and to protect against SPEs. Dr. Simonsen discussed the balance between physical and biological radiation protection. She explained that NASA is analyzing the space radiation shielding for Exploration spacecraft. In response to a question from Dr. Jernigan, Dr. Simonson discussed space weather forecasting, using crew location for operational mitigation, and conditions that would necessitate having the crew take shelter.

Dr. Simonsen described the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory and presented a chart on Mars Mission GCR simulation. Dr. Simonsen concluded her presentation by noting that there is an assessment underway of space weather and forecast architectures to support future human and robotic exploration of deep space.

Dr. Peterson thanked Dr. Simonsen and Dr. Zeitlin for their presentations.

Public Comments

Mr. Bowersox invited comments from the public.

There were none.

Discussion and Recommendations

Mr. Bowersox invited the committees to make suggestions for findings and recommendations. Mr. Hale advised that the optimal approach to addressing the radiation hazard would be to reduce the astronauts' exposure times. He observed that NASA has "hung our hat for years on the magic radiation shield." Dr. Simonsen added that the "magic shield" will not show up. Mr. Bowersox agreed that it is important to look at faster transit rates. Dr. Walter Secada asked what the increased cancer risk is from smoking one pack of cigarettes a day. Ms. Joan Zimmermann responded that overall lifetime risk of a smoker developing lung cancer is roughly 15%, compared to that of a nonsmoker. Dr. Siegel advised that women are more sensitive to the risk of cancer from radiation exposure than men, and that the risk gets lower as women age. One reason for women's increased risk is due to breast cancer.

Mr. Bowersox presented a proposed joint finding on how well HEOMD and SMD are working together. After discussion and minor modifications, the committees approved the following joint finding:

HEOC/SC Joint Finding: Cooperation Between HEOMD and SMD

Finding:
It is clear from the presentations and discussions during the joint session of the HEO and Science Committees that the HEOMD and SMD are working well together and have already identified opportunities for cooperation on future activities such as the Deep Space Gateway and servicing and possible future assembly of deep-space telescopes. Both committees believe that this collaboration is beneficial to NASA.

Dr. Peterson presented a proposed joint finding about the FASST work on servicing and assembling satellites while in orbit. After discussion and minor modifications, the committees approved the following joint finding:

HEOC/SC Joint Finding: Servicing and Assembly of Satellites On-Orbit
(Request Transmission to HEOMD AA and SMD AA)

Finding:
Both committees were pleased that the servicing and assembly of large satellites, such as future deep space telescopes or other scientific instruments, is being explored by groups internal to NASA as well as groups representing broader communities that include NASA representation. The HEO and Science Committees believe that these efforts are valuable contributions for planning for the Deep Space Gateway (DSG) which could enable or enhance on-orbit servicing or assembly of future space assets and potentially lower costs for large satellites.

The committees agreed that science was being well integrated in the human exploration plans outlined, and approved the following joint finding:

HEOC/SC Joint Finding: Deep Space Gateway Workshop
(Request Transmission to HEOMD AA and SMD AA)

Finding:
Both committees commend NASA's efforts to maximize the science benefit of the Deep Space Gateway as specified in the existing Decadal Surveys and other key NASA science planning documents.

Mr. Bowersox presented a proposed joint finding on the fact that deep space transit radiation exposure leads to an approximately ten percent increased life-time cancer risk. The committees discussed whether this instead should be a recommendation. Mr. Hale presented a proposed recommendation to the Administrator to mitigate radiation by accelerating efforts to reduce transit time. After discussion and minor modifications, the committees approved the following joint recommendation:

HEOC/SC Joint Recommendation: Mitigating Space Radiation Risk

Recommendation:
The committees recommend that NASA accelerate efforts to reduce the radiation risk for future crews by exploring novel concepts for radiation shielding and improving deep space propulsion that would reduce transit time.

Major Reasons for the Recommendation
The Science and HEO Committees met jointly to get an update on the expected radiation exposure for deep space missions.
Current data shows that the deep space transit to Mars would expose the crew to roughly two to three times the radiation dose received on a similar mission aboard ISS, and approximately the same level exposure as ISS while on the surface of Mars. For a two to three year transit to and from Mars as currently envisioned for the deep space transport, an increase in lifetime cancer risk of approximately 10% would be expected for the crew members.

Consequences of No Action on the Recommendation
Greater health risk must be accepted for Mars human exploration missions.

Adjourn

Dr. Siegel thanked everyone at the National Institute of Aerospace and NASA LaRC for their help in making the meeting successful. She thanked the Committee's support staff for their efforts. Dr. Siegel adjourned the meeting at 5:05 p.m.

Human Exploration and Operations Committee
Langley Research Center
National Institute of Aerospace
Hampton, VA

July 24-25, 2017

MEETING AGENDA

Monday July 24, 2017

NAC HEO COMMITTEE PUBLIC MEETING

10:30 – 10:35	Call to Order, Welcome & Opening Remarks	Mr. Ken Bowersox & Dr. Bette Siegel
10:35-11:30	Human Exploration & Operations Mission Directorate	Mr. Greg Williams
11:30-12:30	ISS update and accomplishments	Mr. Sam Scimemi
12:30- 1:30	***Lunch***	
1:30 – 2:30	Exploration Systems Division	Mr. Marshall Smith
2:30- 3:30	Commercial Crew	Mr. Steve Stich
3:30-3:45	***Break***	
3:45- 5:00	Discussion and Recommendations	
5:00	***Adjourn***	

Tuesday July 25, 2017

NAC HEO COMMITTEE / SCIENCE COMMITTEE PUBLIC MEETING

9:00 – 9:15	Opening Remarks for Joint Session	Dr. Bette Siegel / Mr. Ken Bowersox / Ms. Elaine Denning / Dr. Bradley Peterson
9:15 – 12:15	*HEO and Science Emerging Opportunities*	
9:15 – 10:15	HEO Future Exploration Plans	Mr. Greg Williams
10:15 – 12:15	Science Opportunities	
10:15 – 11:00	Science Opportunities Overview	Dr. Thomas Zurbuchen
11:00 – 11:10	***Break***	
11:10 – 11:45	Future Telescopes Human Servicing	Dr. Jeffrey Hoffman Mass. Instute of Technology
11:45 – 12:15	Future Assembly and Servicing Study Team	Dr. Ronald Polidan Polidan Science Systems & Technologies, LLC.
2:15 – 1:15	***Lunch***	
1:15 – 2:15	Science Enabled by Human Exploration	Dr. Ben Bussey
2:15 – 2:30	Break	
2:30 – 3:30	Space Radiation	Dr. Lisa C. Simonsen, Dr. Cary Zeitlin
3:30 – 3:35	Public Comment	
3:35 – 5:15	Discussion, Findings, and Recommendation	
5:15	***Adjourn***	

Human Exploration and Operations Committee Membership
July 2017

Mr. Ken Bowersox, *Chair*	Former NASA astronaut and retired U.S. Navy Captain
Dr. Bette Siegel *Executive Secretary*	NASA Headquarters
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. Bob Sieck	Former Space Shuttle Launch Director
Mr. Gerald Smith	Former Deputy Director, Stennis Space Center
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
Langley Research Center
National Institute of Aerospace
Hampton, VA

July 24-25, 2017

MEETING ATTENDEES

HEO Committee Members:

Bowersox, Kenneth, *Chair*	Aerospace Consultant
Siegel, Bette, *Executive Secretary*	NASA Headquarters
Bartell, Shannon	Aerospace Consultant
Condon, Stephen "Pat"	Aerospace Consultant
Cuzzupoli, Joseph (via telecon)	Aerospace Consultant
Gardner, Ruth	Aerospace Consultant
Hale, Wayne	Aerospace Consultant
Sieck, Robert (via telecon)	Aerospace Consultant
Smith, Gerald	Aerospace Consultant

Science Committee Members at Joint Session:

Peterson, Bradley, *Chair*	Ohio State University
Denning, Elaine, *Executive Secretary*	NASA Headquarters
Avery, Susan	Woods Hole Oceanographic Institution
Boss, Alan (for B. Scott Gaudi)	Carnegie Institution
Desai, Mihir	Southwest Research Institute
Flanagan, Kathryn	Space Telescope Science Institute
Jernigan, Tamara	Lawrence Livermore National Laboratory
Liemohn, Michael (for Jill Dahlburg)	University of Michigan
Robinson, Mark S.	Arizona State University
Secada, Walter	University of Miami
Shepherd, J. Marshall	University of Georgia
Verbiscer, Anne	University of Virginia

NASA Attendees:

Belvin, Harry	NASA LaRC
Bussey, Ben	NASA Headquarters
Crusan, Jason	NASA Headquarters
Gaddis, Steve	NASA LaRC
Gates, Michele	NASA Headquarters
Hill, Bill	NASA Headquarters
Jermstad, Wayne	NASA Johnson Space Center

Lawson, Donna	NASA LaRC
Mangrum, Diamond	NASA – student
Mark, Sherry	NASA LaRC
Mazanek, Dan	NASA LaRC
McLeod, Catherine	NASA JSC
Neil, Doreen	NASA
Pahlavani, Patricia	NASA LaRC
Roberts, Bhashar	NASA
Scimemi, Sam	NASA Headquarters
Simonsen, Lisa	NASA LaRC
Stitch, Steve	NASA Headquarters
Tomek, Deb	NASA LaRC
Williams, Greg	NASA Headquarters
Zurbuchen, Thomas	NASA Headquarters

Other Attendees:

Frankel, David	PB Frankel, LLC
Hale, Wayne	NASA Advisory Council
Hoffman, Jeffrey	MIT
Polidan, Ronald	Polidan Science Systems & Technologies L.L.C.
Sanders, Patricia	Aerospace Safety Advisory Panel
Verbiscer, Anne	UVA
Zeitlin, Cary	Lawrence Berkeley National Laboratory

TELECON ATTENDEES

Angie Jackman	NASA MSFC
Bill Stabnow	NASA
Bouknight-Hamilton	Orbital ATK
Branscome	NASA Consultant
Carol Warner	NASA
Charles Lillie	Lillie Consulting
Chris Gilbert	GE Consult
Chris Moore	NASA
Citizen	Independent
DaMara Belson	NASA
Dan Lester	Exinetics
Dan Vergano	Buzz Feed News
Danielle Montecalvo	National Academies
Dave Huntsman	NASA Glenn Research Center
David	Unaffiliated
David Eisenman	NASA JPL

Deborah Tomek	NASA
Edwin Hubble	
Eileen Stansbery	NASA HQ
Emre Kelly	Florida Today
Ethan Hopper	SpaceX
Gale Allen	NASA HQ
Harley Thronson	NASA Goddard
Helen Grant	NASA HQ
James Lochner	USR
James Zimmerman	NASA Retired
Jay Jackson	NASA HQ
Jeanette Domber	Ball Aerospace
Jeff Foust	Space News
Jeff Hoffman	MIT
Jeffrey Newmark	NASA
John	SETI Institute
John Dyster	Orbital ATK
John Rummel	SETI Institute
Kathleen Boggs	NASA
Kathryn	NASA
Kevin Metrocavage	NASA
Lester	Xenetic
Louis Barbier	NASA HQ
Louis Barbier	NASA HQ
Lynn Bowman	NASA Langley
MacEwen	Reviresco LLC
Marchel Holle	National Academies
Mark Mozena	United Launch Alliance
Marsha Smith	SpacePolicyOnline.com
Martha Clouwdsley	NASA Langley Research Center
Michael Maloney	National Academies
Mike	Commercial Crew Program
Mike Skrutskie	University of Virginia
Mumford	NASA HQ
NSFC	NSFC
NSFC	NSFC
Paul Hertz	NASA
Peg Luce	NASA HQ
Phil Putter	NASA HQ
Philip Sloss	NASA Spaceflight.com
Rick Irving	NASA
Rowe	NASA HQ

Sandra Graham	National Academies
Siegler	JPL
Stephen Clark	Space Flight Now
Steve Davison	NASA HQ
Walt Faulconer	Faulconer Consulting Group
Werneth	NASA

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LIST OF PRESENTATION MATERIAL

1) HEO Overview and Accomplishments Update (Williams)
2) International Space Station Status (Scimemi)
3) Deep Space Exploration Systems (Smith)
4) Commercial Crew Program Status (Stich)
5) Human Exploration Plans (Williams)
6) Nexus of Science & Human Exploration (Zurbuchen)
7) Servicing Large Space Telescopes (Hoffman)
8) Future Assembly/Servicing Study Team (Polidan)
9) Workshop on Science in Cislunar Space (Bussey)
10) Mars Radiation Environment – What Have We Learned? (Simonsen & Zeitlin)