National Aeronautics and Space Administration
Washington, DC

NASA ADVISORY COUNCIL

Human Exploration and Operations Committee

April 7-8, 2015

NASA Headquarters
Washington, DC

MEETING MINUTES

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Kenneth Bowersox, Chair

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Bette Siegel, Executive Secretary

Human Exploration and Operations Committee
NASA Headquarters
Washington, DC
April 7-8, 2015

MEETING MINUTES
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NASA ADVISORY COUNCIL
Human Exploration and Operations Committee

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Washington, DC 20546

PUBLIC MEETING
April 7-8, 2015

Tuesday, April 7

Call to Order, Welcome, and Opening Remarks

Dr. Bette Siegel, Executive Secretary for the NASA Advisory Council (NAC) Human Exploration and Operations (HEO) Committee, called the public session of the HEO Committee to order at 10:00 a.m. She announced that the meeting was a Federal Advisory Committee Act (FACA) meeting and, therefore, would be open to the public. Minutes would be taken and posted online. There would be an opportunity for the public to make comments towards the end of the meeting, and she asked for any questions or comments to be held until that time. Dr. Siegel noted that the HEO Committee would be joining the NAC Science Committee at 1:00 p.m. for a joint meeting.

Mr. Kenneth Bowersox, HEO Committee Chair, welcomed everyone and introduced the first speaker, Mr. William Gerstenmaier, Associate Administrator, Human Exploration and Operations Mission Directorate (HEOMD).

Status of Human Exploration and Operations

Mr. William Gerstenmaier provided a directorate-level overview. He noted that his first slide, "Journey to Mars," was a public outreach chart. Its purpose is to stress the journey aspect, which will take multiple decades. It is not only human exploration; it will involve science and technology as well. The chart also showed various pieces of hardware—some in existence today. The theme spans three "regions." The first is the Earth Reliant region where missions are six to twelve months long and crew return to Earth takes hours. Mr. Gerstenmaier emphasized that we can learn much from the International Space Station (ISS) in this region, e.g., the one-year astronaut expedition that is currently on-going. The second region is the Proving Ground. This region is in cis-lunar space where missions are one to twelve months with crew return to Earth taking several days. In the Proving Ground, NASA and its partners will build on operational techniques developed on space station, advancing and practicing them for longer-duration deep-space missions. The last region is Earth Independent where missions are two to three years and return to Earth takes several months. Mr. Gerstenmaier stated that from a risk standpoint, going from Earth Reliant directly to Earth Independent is too large a jump. The Proving Ground will be necessary as an intermediate step.

Mr. Gerstenmaier reviewed the work involved in preparing for commercial crew missions to the space station. ISS is undergoing a major docking system reconfiguration that will be completed by the end of this year. There will be much important work "behind the scenes" to prepare to support the commercial crew work in the future.

Soyuz recently launched with Astronaut Scott Kelly, who has begun a one-year mission aboard the ISS. NASA expects to learn new things about the cardiovascular system and the long-term effects of space flight. The mission will be very intense from a research standpoint, and there will be a very high degree of scientific research coordination between the U.S. and the Russian partner.

With respect to the Commercial Crew Program (CCP), two contracts were awarded for commercial crew certification and transportation services—to The Boeing Company (Boeing) and Space Exploration Technologies, Inc. (SpaceX). Under the contracts, NASA will purchase at least two crew transportation flights from each contractor. Development is scheduled to be complete by 2017, but that date is dependent on adequate budget and forward progress. Mr. Gerstenmaier briefly described the two-phase acquisition strategy. So far, progress has been good, and significant milestones are scheduled for this year. However, if NASA does not receive the full requested funding in Fiscal Year (FY)16, the Agency will have to delay milestones. Mr. Gerstenmaier emphasized that the FY16 budget is one of the most important budgets for this Program and is particularly critical to schedule.

Mr. Gerstenmaier highlighted a number of major milestones in the Space Launch System (SLS) and Orion in 2015. SLS is on schedule to complete its Critical Design Review (CDR) in July. Orion's CDR will occur in October, and the Ground System Development and Operations (GSDO) CDR will occur in December. Mr. Gerstenmaier described the SLS Block 1B and the mission concepts under study. He noted that there is still a lot of work ahead to verify the real capability from an engineering standpoint. He emphasized the new elements in this Solid Rocket Booster (SRB). The entire insulation system inside the booster was changed, saving 2000 pounds with the new insulator. In addition, the manufacturing effort has been reduced dramatically. This is a new booster in terms of weight and material.

Although Mr. Gerstenmaier's presentation included slides on the Asteroid Redirect Mission (ARM), he noted that Dr. Michele Gates's briefing later in the meeting would provide much more detail on this subject. In response to a question from Dr. Pat Condon on the prime factors that led to selection of Option B, Mr. Gerstenmaier explained that extensibility toward the future was one factor; also, Option B provides for better control with regard to the certainty of objects being grasped.

The Launch Services Program (LSP) achieved two very successful launches this year: the Soil Moisture Active Passive (SMAP) mission and the Magnetospheric Multiscale (MMS) mission. Jason -3 is scheduled for launch in July.

Space Communication and Navigation (SCaN) has been very active. The Space Network (SN) is moving forward to provide needed communications and tracking services. Mr. Gerstenmaier noted that NASA is losing some reimbursable funding and will need to make up for this loss in future budgets. He also noted increasing pressure on spectrum allocations. Currently, NASA is protecting bandwidth, and there is a lot of work being done behind the scenes.

With respect to "Pioneering Space," Mr. Gerstenmaier closed his briefing with a quote from President Obama's speech in April 2010:

> *Fifty years after the creation of NASA, our goal is no longer just a destination to reach. Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite. And in fulfilling this task, we will not only extend humanity's reach in space—we will strengthen America's leadership here on Earth.*

Questions/Comments:
Mr. Gerstenmaier emphasized that the Committee would receive considerable detail from the presenters later in the meeting. In response to a question from Mr. Bowersox, he noted that he would like to release the "Pioneering Space" report in the summer timeframe this year. The report will receive fairly extensive internal and external reviews. It is intended to be the "plan for the plan." Mr. Greg Williams commented that they are trying to make it an Agency document, not just a HEOMD document. "Humans to Mars" is a unifying strategy. In response to a question about what has been causing the delay in the release of the report, Mr. Gerstenmaier explained that the delays have been internal to NASA. They want to complete some analyses and learn some things going through the budget process. They want to make it as detailed as possible, but don't want to get too locked into specific scenarios. The content has been changed a couple of times, along with some of the studies. They want to make it a meaningful document, clearly thought out, and with the trades analyzed. There is not any real need to push it out quickly, but this summer will be the right time to release it.

FY 2016 Budget Overview

Mr. Gerstenmaier presented the overview on the budget for Ms. Toni Mumford, Director of the Resource Management Office and her team, who were currently working on the FY 2017 budget. He discussed ISS, Commercial Crew, Exploration Systems Development (ESD), Exploration research and development, and space flight support.

The FY16 budget submit provides $8.5 billion (B) for HEO, consistent with the NASA Authorization Act of 2010. Both the House and Senate have new Authorization Acts, and there are many interesting reports on the findings in those documents. Mr. Gerstenmaier enumerated everything contained in this budget: sustaining the capability for long-duration presence in low-Earth orbit (LEO); expanding permanent presence beyond LEO; enabling missions to deep space destinations; providing critical communication, navigation, launch, test, and other services; extending ISS life to at least 2024 and enabling continued research; funding ISS commercial cargo resupply services and partnering with industry to develop capabilities for commercial crew systems; funding next generation launch and crew vehicles and associated ground systems; supporting human health and technological research for deep-space exploration; and continuing the modernization and enhancement of capabilities critical to operations and exploration in and beyond LEO.

Mr. Gerstenmaier showed the details of the FY16 budget, including the lines for FY14 and FY15. The major increase in budget in FY16 is for CCP. Most of the other programs are essentially flat. HEOMD must balance the budget within the overall guidance. Most of the increase for ISS is in the crew and cargo transportation line. In response to a question, Mr. Gerstenmaier noted that FY15 reflects the appropriation; however, the chart did not show the operations detail for FY15, because NASA is not permitted to display that detail until it is approved by Congress. Mr. Gerstenmaier noted that another important "takeaway" from this budget is that he does not have a lot of flexibility; the allocations are given to NASA in Congressional language. The budget also includes funding for fixed-price contracts that are "must pay" bills.

Mr. Gerstenmaier discussed the ISS plans for FY15 and FY16: reaching out to commercial companies through the Center for Advancement of Science in Space (CASIS), completing development and beginning operation of the NASA GeneLab database in 2015, and enabling new lab research on ISS to aid in human research. Many companies are now doing research in space; however, while there is large breadth, there is still not much depth. At the corporate level, companies have not yet seen the benefits of space research. CASIS is continuing to reach out to the commercial sector. The opportunity for innovation on ISS is huge. Dr. David Longnecker reinforced comments regarding the potential terrestrial application of the ocular research. It will be an important step forward – a non-invasive way to detect intracranial pressure. Also, ISS research has spurred tools for the layperson to use ultrasound. Mr. Gerstenmaier noted that there has been tremendous outreach through NASA's partnership with the American Society of Mechanical Engineers (ASME) to issue "Future Engineers" 3-D print design challenges to students, with winning designs selected to be printed by astronauts aboard the space station. NASA licensed its own technology to Bigelow Aerospace to conduct the Bigelow Expandable Activity Module (BEAM) demonstration to understand deep space habitat options. The module is expected to launch to station on SpaceX's eighth Commercial Resupply Services mission later this year. Other activities include: using returning Cygnus flights to assess large scale microgravity fires, continued solar array activity on ISS, and continued operations of the Alpha Magnetic Spectrometer (AMS). Mr. Gerstenmaier noted that his team is starting to see a lot of interesting uses of ISS for Earth observations. He also highlighted plans for several other studies, experiment development, and prototyping.

At the top level, Mr. Gerstenmaier reviewed the FY15 and FY16 plans for the CCP, leading to a certification of the partner vehicles in 2017. The two Commercial Crew Transportation Capability (CCtCap) contracts total $6.8 B: $2.6 B to SpaceX and $4.2 B to Boeing. Mr. Gerstenmaier again emphasized how critical it is that the CCP receive the full FY16 President's Budget Request to support the planned milestones and certification by 2017. He noted that it is very difficult to do a direct price comparison between Soyuz and Commercial Crew. Soyuz seat pricing has

increased about nine percent per year. NASA is in the process of working on contracts for seats into 2018. Mr. Bowersox added that another important advantage for commercial crew is that the crew can increase to seven. This provides NASA additional flexibility. Mr. Gerstenmaier presented a chart to help explain why NASA needs the CCP funding increase. The majority of funding is captured in the CCtCap milestones.

Mr. Gerstenmaier provided an update on ESD, beginning with a top-level mission overview. He described the ESD integrated manifest: Exploration Mission (EM)-1 beyond-Earth orbit (BEO) uncrewed; the Launch Abort System Test Article (AA-2), and EM-2 BEO crewed configurations. In response to a question regarding the difference in mission choices between the Exploration Upper Stage (EUS) and the Interim Cryogenic Propulsion Stage (ICPS), Mr. Gerstenmaier explained that the ICPS does not have as much lift capability as the EUS. Another factor is the value for the cost. NASA has not chosen to human rate the ICPS because it is acceptable to launch the uncrewed EM-1 with it; however, there would be non-trivial costs associated with human rating. For the dollars, the Program would rather human rate the EUS. The goal is to have the EUS for EM-2, but the Program currently does not have funding for that. At present, the team is putting design trades in place and getting ready for an engine EUS selection in next few months. This is clearly where NASA wants to go; it is just a question of funds. Mr. Bowersox added that there are some risks associated with EUS, e.g., flying crew for first time on a new upper stage. Mr. Gerstenmaier felt that the crew risk is minimal – if EUS doesn't work properly, the crew can recover. NASA can control crew safety risks; the mission success risk is more of a concern. Technically, the Program would prefer to go after development now, get that behind them, and obtain long-term cost savings. HEOMD will make a recommendation to the Administrator near end of this year. In response to a question from Mr. Bowersox on what NASA would do if it had to use ICPS indefinitely, Mr. Gerstenmaier replied that this would not be good for low lunar orbit; the EUS capability is needed for that. EUS allows the building of capabilities in the Proving Ground. If NASA doesn't get the funding, the Agency would be looking at more launches to do something else.

Mr. Gerstenmaier reviewed the results from Exploration Flight Test (EFT)-1. Overall, it demonstrated better performance than expected in many areas. The only anomaly was related to the bag deployment in the crew module up-righting system. NASA is still looking through all the data, but everything shows positive to date.

The FY15 Orion plans are moving along well with the European Service Module. The design is complete and manufacturing has begun. There will be considerable Orion activity in FY15 and FY16.

Mr. Gerstenmaier reviewed FY15 plans and challenges for the SLS. He noted that the Agency has not been engaged in a major space system development phase for many years. However, the Program has margins in place both in budget and schedule to accommodate the normal development challenges.

Mr. Gerstenmaier highlighted the FY15 and FY16 plans for GSDO. In FY15, the structural and facility modifications will be completed, and NASA will begin ground support equipment for the mobile launcher. Platform construction continues in the Vehicle Assembly Building (VAB). FY16 will see completion of the CDR to evaluate the ground systems design integrity and ability to meet mission requirements. Construction and installations will conclude and NASA will begin test of the command, control, and communications systems software.

Mr. Gerstenmaier discussed the Advanced Exploration Systems (AES) FY15 plans. NASA will need to make decisions soon on the next generation suits for ISS and exploration. He noted that Mr. Jason Crusan would talk later in the meeting about the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA) awards and that Dr. Michele Gates would give the Committee all the details on the ARM. He noted that considerable amount of the ARM budget profile is leveraged with the Space Technology Mission Directorate (STMD). The HEOMD-unique funds are relatively small compared to the leveraged portion. The challenge will be to ensure that the right dollars are there at the right time.

Mr. Gerstenmaier highlighted the FY15 and FY16 plans for SCaN and reviewed the rocket propulsion testing plans for FY15 and FY16 at Stennis Space Center (SSC), White Sands Test Facility (WSTF), Marshall Space Flight Center (MSFC), and Glenn Research Center (GRC) Plum Brook Station. He noted that one of the big challenges with testing

facilities is to keep them around until you need them. There are difficult management challenges associated with keeping facilities in some state of readiness without overspending.

Mr. Gerstenmaier showed the LSP manifest for FY15 through FY21. He also highlighted space flight crew operations plans for FY15 and FY16. In terms of crew health and safety, there is an astronaut occupational surveillance activity. Surveillance tasks and mitigation development are the result of partnering efforts among the ISS, the Human Research Program (HRP), AES, and Crew Health and Safety. Mr. Gerstenmaier noted the crew health and safety plans for FY15 and FY16.

The 21st Century Space Launch Complex at Kennedy Space Center (KSC) will continue its plans to modernize and upgrade the launch complex systems and range assets. Wallops Flight Facility (WFF) will also continue upgrades and improvements to its launch complex during FY15 and FY16.

Questions/Comments:
In response to a question from Mr. Robert Sieck on whether he could provide any rough-order-of-magnitude (ROM) number or the percentage of budget that goes into developing capability for humans to Mars, Mr. Gerstenmaier indicated that he didn't have that, but he and Ms. Toni Mumford would think about it. He took an action to get the number/estimate promised earlier. Mr. Gerstenmaier notes that the charts he presented to the Committee are those that he uses to brief the Congressional staff; he invited input from the Committee on how to more effectively convey the budget story and better communicate what HEOMD is doing and how the dollars are being spent.

In response to Mr. Bowersox's question on what the top challenges are other than ICPS and CCP, Mr. Gerstenmaier replied that those are his biggest concerns. The other problem is losing flexibility overall. With respect to SCaN, he no longer has reimbursables in many areas, and NASA must make up for the budget shortfall. Tracking and Data Relay Satellite (TDRS)-M is completed, but there is not a launch vehicle for it. SGSS exceeded its budget cap, and he needs to work through that. SCaN has high availability and high user success, but may be starting to trend toward issues with preventive maintenance. Also, Congress directs HEOMD to do things that don't really fit into the budget, and NASA does not receive additional dollars for them. Mr. Gerstenmaier said that he sometimes jokes that he has an $8 B budget but he has $10 B worth of content. There are many audits that tell him that he is not maintaining networks correctly, that he does not have not enough robustness in the system, and that he does not have enough margin; in other words, not enough resources to do all the work. He acknowledged that he is sympathetic to what they are saying, but he cannot budget for worst on worst on worst nor can he tolerate reserve for all risks. He stated that we must be willing to take budget risks as long as we understand what the consequences are and can provide mitigations for them. He indicated that he is prepared to execute for the worst case failures. The auditors don't like that; they still want full capabilities. Mr. Gerstenmaier stated that he is running out of "creative management" techniques. The Agency struggles with having more facilities than needed to do the missions. The budget in AES is predominantly civil servants, and Mr. Gerstenmaier is able to creatively utilize the workforce. However, there are not a lot of procurement dollars to buy hardware and equipment. His challenge is to try to successfully convey the complexity of what HEOMD is trying to do. Externally, many do not recognize what it means to be "in development."

Ms. Toni Mumford provided the answer regarding budget flexibility: in FY15, it is about $88 million (M), which is a little over 1 percent. She noted that even this is not true flexibility, but it is better than zero. Mr. Gerstenmaier indicated that he has threats across multiple programs that are balanced against the same budget. He added that certain things are absolutely protected, e.g., crew health on Station and ISS operations.

Mr. Gerstenmaier again invited help from the Committee on how to better talk about the budget and what it covers.

JOINT MEETING

Call to Order and Welcome

Dr. Siegel called the public session of the joint meeting of the HEO Committee and the NAC Science Committee (SC) meeting to order at 1:00 p.m. She announced that the meeting was a FACA meeting and open to the public. Minutes would be taken and posted online, along with the presentations. There would be an opportunity for the public to make comments towards the end of the meeting. She asked that questions and comments be held until that time.

Opening Remarks and Member Introductions

Dr. David McComas, Chair of the SC, welcomed everyone to the joint committee meeting. He noted that one of the biggest issues for long-duration space flight beyond the magnetosphere is that of space radiation. This is a topic in which both the SC and the HEO Committee have an interest. Mr. Bowersox agreed that this is a very important topic and welcomed the opportunity for the joint session with the SC. At his request, the members from the HEO Committee identified themselves.

Space Radiation and Discussions

Mars Mission and Space Radiation Risks Overview

Dr. Steve Davison, Program Executive for the HRP, introduced the topics that would be briefed by the NASA and university experts following his overview. His overview focused on the ongoing NASA research program and the activities that are contributing to mitigation of health risks from space radiation exposures. He noted that the presentations would include topics on the space radiation environment, radiation health risk projections, and research and technologies for risk mitigation. The NASA programs and approaches (and their research underpinnings) that address the space radiation health risks have been extensively vetted by the National Academies. The technical content of the programs are aligned with their recommendations. Dr. Davison noted that "NASA programs" includes all of the researchers external to the Agency. These programs are critical to providing the best assessment to inform crew members, the Office of the Chief Health and Medical Officer (OCHMO), and senior management, as well as for developing the best mitigations.

All of the health risks in human space exploration have been identified, and medical standards are in place for most of the significant risks. The human research roadmap lists all of the human health risks, all of the evidence base for those health risks, the research gaps for each health risk, and the current tasks. Dr. Davison stated that based on the Human System Risk Board (HSRB) assessment of the risk posture, at this time there are no crew health risks that are considered "mission-stoppers" for a human mission to Mars. The biggest challenge is additional exposure to radiation and the chance of developing a radiation-induced cancer. Committee members discussed the terminology "mission-stopper" and what that means. Dr. Davison explained that there is a lot of research and work on mitigation plans; the HSRB looks at all of that. In other words, NASA sees a path forward, but needs to do considerable research towards mitigation plans. Dr. Jeffrey Davis, Chief Medical Officer at Johnson Space Center (JSC), added that NASA has identified the risks and the work that needs to be done. The Agency sees a path forward to mitigation of the risks. In response to a question regarding how NASA tracks the drivers through to the mitigations, Dr. Davison noted that this is an area for systems engineering. There will be trade-offs, but crew health and safety is the number one priority. He noted that many of the Committee questions would be answered or addressed in the subsequent briefings.

For solar particle events (SPEs), NASA can manage and deal with those through shielding and "storm sheltering." Most of the challenge is in low-dose cosmic rays, which will not have a mission impact but can present risks to long-term health. In response to a question, Dr. Davison agreed that space radiation is still carried as "red" on the risk chart, because NASA cannot meet the current medical cancer risk standard today.

Dr. Davison highlighted the human space flight risks that are driven by space flight hazards. The HSRB has been able to produce a summary list. These 30 risks are grouped into 5 categories: altered gravity field, radiation, distance from Earth, isolation, and hostile/enclosed environment or spacecraft design. Based on the HSRB assessment, the risks that are the most significant for a Mars mission have been identified. These are broken down into "in-mission" risks and "post-mission" risks. Dr. Davison showed the current space flight health standards. NASA should be able to meet all fitness for duty (FFD) and permissible outcome limits (POL) standards for a Mars mission. Meeting the current LEO space radiation Permissible Exposure Limit (PEL) standard will be challenging for a Mars mission. He noted that the PEL standard drives a lot of the research and activities. NASA looks at space radiation health risks in four areas: carcinogenesis, acute radiation syndromes from SPEs, degenerative tissue effects, and central nervous system risks. Research is just starting in some of the non-cancer areas. Currently, cancer risk is the limiting risk. Dr. Davison briefly discussed the Mars mission cancer risk calculations. In response to a question, Dr. Davison indicated that NASA is mostly worried about the higher energies. The NASA standards limit the additional risk of cancer death by radiation exposure, not the total lifetime risk of dying from cancer. For non-smokers in the general population, the baseline lifetime risk of death from cancer is 16 percent for males and 12 percent for females. After a Mars Mission (at solar max), the astronauts' lifetime risk of death from cancer is about 20 percent. This is above the 3 percent standard. There was some Committee discussion about the basis and underpinnings of the 3 percent standard (normal, ground-based radiation protection). Dr. Davison observed that it is very challenging to do population-based models when there will be a very limited set of individuals who will be on a Mars mission.

NASA has an integrated portfolio to optimize human radiation protection, including countermeasures, nutrition, operational modes, shielding, occupational surveillance, etc. NASA is working across all phases of the Mars mission—pre-mission, in-mission, and post-mission—to minimize the space radiation health risk. Dr. Davison cited examples of activities to reduce radiation health risks. In summary, based on current mitigation plans for crew health and performance risks, NASA can support a Mars mission. However, based on the present understanding of risks and standards, the radiation standard would not currently be met. In response to a question about the NASA Space Radiation Laboratory (NSRL), Dr. Davison indicated that other organizations use this facility. NASA could not afford such a laboratory on its own. Dr. Davison briefly noted some of the work done at the NSRL.

Health Standards Decision Framework

Dr. David Liskowsky from NASA's OCHMO discussed the Institute of Medicine (IOM) report, "Health Standards for Long Duration and Exploration Spaceflight: Ethics Principles, Responsibilities, and Decision Framework," and the OCHMO's implementation plan. The report, released in April 2014, made four recommendations. The first three recommendations were directed at how OCHMO develops and implements health and medical standards. The fourth recommendation provided a decision framework that can be used when a health/medical standard cannot be met. From a medical perspective, the most important principle is to avoid harm; other principles are beneficence, a favorable balance of risk and benefit, respect for autonomy, fairness, and fidelity. Additionally, there are responsibilities that go along with developing medical standards and implementing them. In order to accept additional risk, the Agency must continue to work on mitigating the risk. The IOM Committee looked at options when a standard cannot be met. It concluded that the only ethically acceptable option that could allow for increased risk exposures in the context of long-duration and exploration space flight is granting an exception to existing health standards. Excepting standards in these situations should be "used under very limited circumstances following the ethics-based framework recommended." Dr. Liskowsky discussed the process and criteria for granting exceptions. The report recommendation was to "adopt an ethics-based decision framework." To do this, NASA should apply the relevant ethics principles and fulfill the concomitant responsibilities through a three-level framework. The OCHMO concurred that excepting health standards should be used under very limited circumstances and would only be executed at the Agency level after careful assessment of the risks and benefits with ethical principles guidance. The exception would not represent a "standard medical waiver." NASA is working on processes for implementing all three levels of decision making. In response to a question, Dr. Liskowsky explained that the processes that would go into a standard medical waiver are different. Dr. Richard Williams, NASA Chief Health and Medical Officer (CHMO), noted that excepting health standards for an exposure is not a waiver for a medical condition. He explained the difference between the standard medical waiver and a waiver to an exposure. The latter becomes a policy decision at the highest levels of the Agency. Dr. Liskowsky added that at

this point in time, NASA has been able to meet the standard of exposure in LEO. He also emphasized the importance of continuing work on mitigations. The OCHMO is currently in the process of developing procedures for the recommendations. In response to a question, Dr. Liskowsky agreed that if NASA knows that it would exceed the standard, there would have to be volunteers. He was asked to comment on whether or not the OCHMO has considered an alternative approach, e.g., with regard to crew selection. He noted that it has been discussed in the Agency, but in terms of the specific report, it was not addressed. In response to a question about the NASA responsibilities for long-term medical care, Dr. Liskowsky replied that from an ethical and principles aspect, the answer would be yes, it is something NASA should do, but other factors impact on NASA's abilities in this area. Dr. McComas noted that the NAC would be looking into this subject and possibly formulating a recommendation.

Space Radiation Environment

Dr. Chris St. Cyr from Goddard Space Flight Center (GSFC) discussed two of the sources of space radiation in the natural environment: solar energetic particles (SEPs) and galactic cosmic rays (GCRs). The Sun is a magnetically variable star, and the solar activity cycle modulates SEPs. Most SEP events occur during solar maximum. The solar activity cycle also modulates GCRs, and most of these occur during solar minimum. Dr. St. Cry discussed the question: How well can we predict the solar activity cycle? He showed a graph plotting the 102 predictions of solar cycle 24. The answer to the question is "not very well."

The Solar Energetic Particle Radiation Hazard

Dr. Allan Tylka from GSFC discussed how the SEP events of solar cycle 24 differ from those of earlier solar cycles and showed data from cycles since 1970. As an example, Dr. Tylka showed the effect of single event upsets (SEUs) in the solid state recorder (SSR) on the Solar and Heliospheric Observatory (SOHO) at the First Lagrangian Point (L1). He provided a brief review of the SEP radiation hazard; a comparison of SEP productivity in cycle 24 versus cycles 21, 22, and 23; and speculation on whether cycle 24 is the "new normal." He noted that the SEP radiation hazard is "out of phase" with the GCR radiation hazard. Biology is the biggest uncertainty in assessing the SEP radiation hazard for astronauts. Astronauts can be "shielded" from the episodic SEP radiation hazard, but early warning is needed. Dr. Tylka presented charts showing the radiation exposure from the largest SEP events of the space age. He discussed how the SEP radiation hazard is evaluated and characterized. He showed several charts displaying data plots from Cycles 20 through 24 and the MeV SEP production in years 2 through 7 of each solar cycle. The differences between cycle 24 and cycles 20 and 21 are not as impressive as the difference between cycle 24 and cycles 22 and 23. However, >MeV solar protons at Earth have virtually disappeared in cycle 24.

Dr. Tylka noted that sunspot number (SSN) serves as a general measure of solar activity. He showed plots of SSNs from 1986 to the present day. SSNs have diminished; however, SSNs per se cannot be used as a predictor of SEP production. Cycle 24 is not yet over, but the SSN is declining from a maximum in April 2014. Dr. Tylka cited examples of previous cycles with a maximum SSN <100.

In summary, Dr. Tylka noted two big "ifs:" If cycle 24 presages a new type of solar behavior that will continue for decades, the relative importance of the SEP radiation hazard will be reduced; if the Sun is no longer producing the very large ground-level events (GLEs) seen in 1959-2006, the required storm-shelter shielding will be greatly reduced. These reductions in the SEP-radiation hazard, combined with the increase in the GCR-radiation hazard, might make solar maximum a better timeframe for long-duration human missions.

Comparison and Validation of Galactic Cosmic Ray Models

Dr. Tony Slaba from Langley Research Center (LaRC) provided a top-level exposure analysis overview and discussed GCR environment and models, radiation transport through shielding, and projecting exposures for mission analysis and vehicle design. The environment is a broad spectrum of particles. The GCR environment fluctuates between solar min and solar max on an approximate 11-year cycle. Dr. Slaba discussed a variety of models that are used. The Badhwar O'Neill (BON) GCR model is used at NASA as input into radiation transport codes for vehicle design, mission analysis, and astronaut risk analysis. The GCR models are developed and validated by using measurements supported by the Science Mission Directorate (SMD) and others over the past 40 years. Eighty-two percent of the available data comes from the Advanced Composition Explorer (ACE) satellite. There is a gap in the measurement data in terms of the high-energy component. Recent work has significantly reduced model uncertainties by taking

a more rigorous approach to model calibration and validation. This has resulted in BON2014. In comparing other international models, the GCR models tend to agree reasonable well at highest energies where the effects of solar modulation are less pronounced. Continuous, time-resolved measurements at high energies are needed to further reduce uncertainties.

Dr. Slaba described radiation transport. Radiation transport codes are used to describe the processes. The GCR model provides the boundary condition. He discussed the comparisons of various transport codes against state-of-the-art Monte Carlo codes. In terms of validation, something slightly different is done for astronaut risk assessment. End-to-end model results are normalized to area dosimeters on the ISS. Where there are no measurements to normalize, direct model evaluation is used in validation and uncertainty quantification efforts. Comparisons between Mars Science Laboratory (MSL)/Radiation Assessment Detector (RAD) and NASA models are ongoing. Current studies can now utilize a more robust probabilistic approach, allowing estimates to be provided within a certain confidence level. With respect to projecting solar activity, model predictions (even in the near term) are uncertain. For example, predictions of peak sunspot number (made near the end of cycle 23) for solar cycle 24 varied by a factor of 5. The models used at NASA to support mission planning and vehicle design have been integrated into a web-based framework called OLTARIS (On-Line Tool for the Assessment of Radiation in Space). There was some Committee discussion on shielding and storm-sheltering. Dr. Slaba noted that radiation analysis tools used for ISS operations, mission planning, and vehicle design in deep space and planetary surfaces are rigorously developed and validated. Based on recent (30 years) solar activity and available measurements, additional measurements are needed to further reduce uncertainties. Mission planning and vehicle design is moving towards more robust probabilistic approaches.

Implications of the Worsening Galactic Cosmic Ray Environment

Dr. Nathan Schwadron from the University of New Hampshire presented some charts that depicted the GCRs from the galaxy and beyond. He cited his research article on space weather, “Does the worsening galactic cosmic radiation environment observed by CRaTER [Cosmic Ray Telescope for the Effects of Radiation] preclude future manned deep space exploration?” One of the critical factors in the CRaTER mission was understanding the magnetic field and how it varies over long periods of time. Dr. Schwadron showed the plotted data for SSN and magnetic flux balance. He noted that while we know something about the space environment, the reality is that we do not know it very well. One can see the variations in the space environment in looking at the data over the past 10 years. Cycle 24 is a case in point. It is very important to stay guarded with predictions. Dr. Schwadron showed the historic record on the continued decay of magnetic flux in the Dalton-like Minimum. He observed that if these trends are consistent, we will see even lower numbers and therefore higher numbers of GCRs. Dr. Schwadron described the CRaTER concept of operations – it shows how shielding changes the radiation within the body. He discussed the Slab Turbulence Model for modulation of GCRs. The scaling was used to model the changes in GCRs. He also showed the dose rate on the lunar surface for cycle 23 and cycle 24. He noted that if we go into an even shallower solar cycle, we will get even higher levels of dose rates. This is telling us that solar minimums are getting increasingly hazardous.

Dr. Schwadron explained some details about the modeling. In looking at the longer term record, a longer term trend has been deduced from the observed heliospheric magnetic field. This continues the trend observed by ACE and CRaTER. He noted that we may well be headed into a long period where the Sun is quieter than average, but we don’t really know. He did a very simple exercise looking at various limits for risk of exposure-induced death at various ages. Dr. Schwadron showed CRaTER’s 2077-day combined detectors dose rate data and the PREDICCS data showing low probability of SEP events in cycles 23-24. He presented a chart showing a comparison of total radiation dose equivalent measured by RAD to modeled historic SPE events.

Dr. Schwadron emphasized that direct observations are critical for validating models. He noted that we have just gone through the deepest solar minimum and the weakest solar maximum in more than 80 years. However, this does not mean that we will not get hit by a large event. Improved understanding and predictability of SEPs is needed.

Emerging Galactic Cosmic Ray Data from AMS-02

Dr. Veronica Bindi from the University of Hawaii discussed recent findings from AMS-02, a cosmic ray detector, which was installed on the ISS in May 2011. AMS is a U.S. Department of Energy (DoE)-led international collaboration. The 4 years of AMS correspond to 60 billion events. Particle rates vary from 200 to 2000 Hz per orbit. Dr. Bindi briefly described the flight and ground operations. The primary goal of AMS-02 in space is looking for dark matter. AMS looks for precision measurement of the positron fraction in primary cosmic rays of 0.5-350 GeV. In the first 18 months in space, AMS has collected over 25 billion events. Of these, 6.8 million are electrons or positrons. The electron flux and the positron flux are different in their magnitude and energy dependence. Dr. Bindi presented charts showing the flux. AMS-02 is the only detector capable of measuring all the species of cosmic rays at the percent level. The AMS-02 measurements will improve our knowledge about cosmic ray sources, acceleration mechanisms, and propagation. New AMS-02 results will be presented during the European Organization for Nuclear Research (CERN) webcast April 15-17, 2015. Dr. Bindi noted the low energy studies being done at the University of Hawaii (UH). This is a collaboration between the UH group and NASA's Space Radiation Analysis Group (SRAG), led by Dr. Eddie Semones. The main goal of this collaboration is to provide the monthly Proton-Helium-Carbon fluxes measured by AMS-02 from 2011 to 2019 in the energy range from 1 to 10 GV, where the radiation is expected to be the most harmful. The SRAG will use the AMS monthly fluxes to improve the GCR models that are used to predict the radiation dose absorbed by astronauts for ISS operations and long duration missions. Dr. Bindi presented several plotted data charts. Daily SEP fluxes measured by AMS-02 will be provided to the NASA SRAG starting in 2016. In response to a question regarding releasing data, Dr. Bindi indicated that the group wants to make the data public, but the DoE has the lead in the release process. It was noted that there has been an agreement signed by all parties regarding release of data.

Radiation Health Risk Projections

Dr. Edward Semones from JSC began his presentation with an overview of the SRAG flight interfaces and the role of the Space Radiation Health Officer, who is responsible for the radiation health and protection program for NASA's astronauts. Congress has chartered the National Council on Radiation Protection (NCRP) to guide Federal agencies on radiation limits and procedures. The current dose limits correspond to a projection of tissue weighted exposure to a permissible limit of 3 percent fatal cancer at 95 percent confidence. Dr. Semones discussed the short term and non-cancer risks and the mission and vehicle requirements in place. In response to a question, he discussed how those requirements were captured or developed.

Dr. Semones briefly reviewed the sources of exposure—GCRs, SPEs, Mars surface environment, medical, aircraft operations, and prior occupational sources. He highlighted the NASA-relevant NCRP reports and provided some additional detail on the NASA PELs for cancer and short-term or late non-cancer effects. He discussed radiation carcinogenesis and the NASA Space Cancer Risk (NSCR) model that was reviewed by the National Research Council (NRC) in 2012. The model utilizes data from epidemiological sources, terrestrial research, and space radiation research. Dr. Semones discussed examples of model outputs, such as cancer risk versus age. He also covered material on gender dependence (per NCRP commentary 23), individual organ and tissue contributions to cancer risk, NSCR-2012 dosimetry results, individual mission doses and informing crew of radiation risk, and acute radiation effects from a SPE. He showed the record of SPE impacts during the ISS era. He reviewed the Multi-Purpose Crew Vehicle (MPCV) radiation monitoring system concept and the MPCV SPE operational response.

Space Radiation Research and Technologies for Risk Mitigation

Dr. Lisa Simonsen from LaRC discussed the biological perspective of the space radiation problem and the foundation of the Space Radiation Radiobiology Research Plan. The Plan is fully documented and updated annually (http://humanresearchroadmap.nasa.gov). She reviewed the major sources of uncertainty in estimating risks for future exploration missions and described some mitigation approaches. Research is being done at the NSRL at Brookhaven National Laboratory. There is a contract in place to do upgrades to the NSRL, one of which is the Galactic Cosmic Ray Simulator that will be completed in late 2016. One area of research focus is on radiation quality and dose-rate effects on cancer processes with the goal of reducing uncertainty in risk estimates. There have been major findings on cancer risk from the NSRL. Another area of focus is central nervous system (CNS) risk definition and characterization. Dr. McComas commented that we do not know enough about CNS risk at this time to say whether it is a "mission showstopper." In terms of cardiovascular disease, the current research is focused on understanding and quantifying the risk of cardiovascular disease at space-relevant exposures. Dr. Simonsen

discussed Biological Countermeasures Research and Development. The National Cancer Institute (NCI)/National Institutes of Health (NIH) and the Biomedical Advanced Research and Development Authority (BARDA) are expressing interest in effects, opening the possibility of increased collaborative studies. She reviewed some radiation tools for design, analysis, and optimization. She also noted some continuing early innovation programs for high-risk/high payoff ideas to advance active shielding technologies and concepts. In conclusion, Dr. Simonsen summarized the NASA approach to address space radiation, a major challenge to exploration.

Public Comments

Ms. Elaine Denning, SC Executive Secretary, opened the floor for public comments. Ms. Lora Bailey, NASA/Johnson Space Center, stated a concern in the connotation of some cited statements from the original presentations, such as "There are no crew health risks at this time that are considered 'mission-stoppers' for a human mission to Mars," and "The most challenging medical standard to meet for a Mars mission is that associated with the risk of radiation-induced cancer." She also commented that among a list of in-flight risks mentioned, there was no mention of in-flight performance risk due to possible cognition or CNS concerns, and posed the question: Doesn't the cognition/CNS concern fit in this list? She indicated that although she understood why they are representing the material in this manner as quoted, she has a big-picture concern that these quoted statements could be misunderstood and/or misinterpreted by a general audience. She also suggested that there be some consideration to changing the language from stating "there are no crew health risks at this time that are mission-stoppers" to something that indicates that clear plans and risk-reduction efforts are in place which hope to show no crew health-related show stoppers, but that these efforts will need to be concluded over time before we are able to draw formal conclusions. She also emphasized the significance of the language and in the messaging of this very carefully and consistently to all our NASA centers as well as to the public.

There were no other public comments and the meeting was adjourned at 6:30 pm.

Wednesday, April 8

CONTINUED JOINT HEO/SC COMMITTEE MEETING

Call to Order, Welcome, and Opening Remarks

Dr. Siegel, Executive Secretary for the NAC HEO Committee, called the continuation of the public session of the Joint HEO/SC meeting to order at 8:30 a.m. She repeated the previous day's announcement about FACA and that minutes would be taken and posted online. She noted that there would be an opportunity for the public to make comments towards the end of the meeting, and she asked for any questions or comments to be held until that time.

Joint HEO/SC Discussion

Dr. McComas welcome everyone to the joint HEO/SC discussion. He noted that the meeting would be divided into three segments. For the first half hour, he would give all of the members an opportunity to make comments about what they had heard the previous day. For the second half hour, they would split into two integrated groups. The third half hour, everyone would get back together for presentation of proposed findings and recommendations. The following suggestions on possible findings and recommendations were offered.

1) Provide statements on what the group heard the previous day, e.g., good presentations, radiation and mitigation efforts on track, a need to continue research and follow the process to identify risks, and stay alert for things to watch for.
2) Develop a general finding; e.g., the HEO and SC Committees have been impressed with the good work being done in HEOMD and SMD. Dr. McComas indicated that he would like to comment on that for the NAC, and he requested that the groups be specific.
3) Mr. Bowersox suggested that the groups start with a finding, then see if it makes sense to do a recommendation.

For the first half hour, the HEO Committee members and SC members offered their comments.

Mr. James Voss was impressed with all of the presentations. The Committees received a lot of good information. Although everyone was saying that radiation is a problem, Mr. Voss felt that it was not initially presented that way. The standard cannot be met, and astronauts are being put at risk. The message is: radiation in deep space for long duration flights is a real problem. NASA and the research community are doing a lot of good work across the board to rectify this, and everyone is devoted to solving the problem. NASA should have a concise, unified message: this is a problem, but we are going to solve it.

Dr. Condon agreed with Mr. Voss' comments. There is a tremendous amount of work being done to understand the problem, both in significance and magnitude. However, NASA needs to be prepared for the possible situation that the risk is significant, that they will not be able to mitigate all of it, but that doesn't necessarily mean that they stop moving forward with human exploration. NASA needs to be prepared to deal with this. Dr. Condon did not have anything to suggest at this point as finding or recommendation.

Dr. Mark Robinson would like to have seen a presentation on engineering solutions, e.g., an optimal way to do shielding. He followed up on what Dr. Condon said—high risk is part of the equation.

Dr. James Green noted that it will be extremely difficult to make environment predictions for rare, extreme events, although they are trying to plan for that. There have been radiation monitors for a long time on ISS; what is needed are radiation monitors in shielding in deep space to measure what different materials will do.

Dr. Scott Gaudi added that much of the information is based on uncertainties and asked if other information could be brought to bear.

Ms. Shannon Bartell agreed that the beginning presentation seemed to imply no problem, but it presented a framework that is a classical waiver/acceptance process. If NASA it doing a waiver/acceptance process for radiation exposure, then the Agency needs to be clear about that and not give the perception that they are trying to "hide it under the rug." With regard to the research, Dr. Bartell indicated that she was very pleased to see that they are planning to do the right things.

Dr. Carle Pieters remarked that the diversity of input was invaluable. There are lots of variables that are being worked, e.g., architecture, time (not only how long but when, e.g., solar max or solar min), and biology. NASA needs to make sure that they are not averse to acknowledging the risks. The issues are being worked, but there is no resolution at this time.

Dr. Harlan Spence echoed what everyone had said. The presentations demonstrated a deep appreciation of issues and the need for an approach. In the larger community, there may be less appreciation of the scope of what is going on. This is a deeply interdisciplinary issue, and it will gain much benefit from more eyes in the community on it. Dr. Spence favored some type of recommendation that would lead to a more regular and deliberate engagement with the community.

Mr. Sieck also agreed with what had been expressed. With regard to previous human space flight programs, he noted that those in the launch business have received a lot of input on why are we doing this. It would do NASA well to get up front with an "education campaign" with the public on the issues—tell the public that NASA is working on the issues and knows there are risks.

Mr. Michael Lopez-Alegria commented that the presentations were very thorough. It is a very difficult problem, and the error bands are very large. If this is a worthy endeavor, then we have to accept that we will have to do things we have not done in the past. He noted that the presentations cited an effort to codify a post-career medical care program. NASA should provide post-career care for people who participate in risky endeavors. Dr. McComas noted that there is already a recommendation on this to the NAC.

Dr. Robert Kirshner felt that monitoring the solar activity over the next twenty years is something that must be done. We know a lot about stars like the Sun; however, the thing missing from the discussion is the size distribution of these large events. There is a good study of GCRs. The idea of making the biological basis firmer is important, e.g., a longitudinal study with this group. With regard to engineering and shielding, we need to find out if the solutions are real. Experimental or demonstration work needs to be done to verify them.

Dr. McSween echoed the biological comment—not everyone is biologically equipped for long-duration space flight. Sending humans to Mars will be difficult, and NASA should not be "politically correct" in astronaut selection. A number of the medical issues can be mitigated by selecting people genetically predisposed to have less risk.

Dr. Maura Hagan agreed that space radiation is a big problem for human exploration; it is complicated, but a lot of good work is being done. However, the work needs to be expanded. It is an interdisciplinary problem, and we cannot have "stovepipes." NASA would benefit from a lot of "intelligent eyes" looking at the issues. She echoed that it is very important for NASA to be "up front" with regard to radiation risks.

Mr. Holloway was impressed with both the quality and scope of what was heard. In his opinion, the key question is: Is the community working on the right things? He suggested that the Committees focus on what NASA is not doing that it should be doing, rather than debating whether to change the language on how the issue is expressed. He indicated that he did not have any problem with the statement "no show stopper." NASA believes they can solve the problem one way or another, and he was comfortable with the Agency's approach and status.

Dr. Robert Lindberg commented that the presentations were in depth and appropriate. He echoed other members' comments. He particularly appreciated the presentation of the OCHMO on the ethics questions. He agreed with the comment that there may be some current limitations that will affect the Agency in selecting crew based on genome screening. He observed that between now and when crew for a Mars mission is selected, there will be a revolution in human genomics, and everyone should expect that be a factor.

Dr. Leroy Chiao was also impressed with the work than has been done. He agreed with Mr. Holloway that NASA will engineer mitigations the best that it can, then will assess the risk and accept it. He concurred that NASA should put a long-term care program for astronauts in place. Also, NASA should work on new types of shielding mechanisms.

Dr. Longnecker also endorsed what others had said. He added a couple of factors that they did not have a chance to discuss: the extent to which the human exploration aspect has been pursued by multiple external groups. There is a huge amount of work going on to validate and assess NASA's work. For example there is an ongoing longitudinal study of astronaut health. Mr. Longnecker noted that the initial comments the previous day created a little confusion among the Committee members. NASA should take care that they don't cause confusion on the issue. He also observed that the Committees didn't hear how two of the areas--space weather and biological factors--come together. There is probably some linkage within NASA, but if not, there should be.

Dr. Steven Running observed that with a multi-year mission like this, we are lectured every day on nutrition. What are people going to eat on a two-year, deep-space mission? We know that nutrition drives the immune system. Do we know enough about human nutrition to tell us that the immune systems wouldn't degrade? Mr. Bowersox noted that similar research work is being done in nutrition. However, the topic for this meeting focused on space radiation. He agreed that Dr. Running brought up a good point that there are risks in many areas, including nutrition.

The HEO and Science Committee members broke into two integrated working groups to draft findings and recommendations. The focus of one group was on space radiation; the focus of the second group was on the joint work within SMD. Dr. Jeffrey Davis made a comment before the working groups commenced. He noted that NASA tracks and monitors 30 key risks, of which radiation is very important. Each risk has an assessment for both the

mission and long-term health. NASA believes that mission risk is being addressed. However, today, the long-term health risk limit is being exceeded.

After discussion in separate groups, the Committee members reconvened to present their proposed findings and recommendations.

The space radiation weather group emphasized the need to continue and enhance "cross-pollination" of different disciplines and organization, e.g., genomes and radiation exposure. There is a need to continue radiation monitoring instruments in space. It is very useful to hold joint NAC meetings to get this cross-pollination on specific topics such as radiation, and more joint meetings should be encouraged. This group also felt that NASA needs to recognize the importance of basic research, e.g., the behavior of the Sun.

The group offered the following finding or observation:

> *Through the series of joint meetings that the NAC HEO and Science Committees have had, we have seen good collaboration between science, engineering, and operations within NASA and also between NASA and academia. We find that this collaboration leads to broader understanding and better outcomes for both Human Exploration and Science. We see opportunity for more synergy and encourage enhanced and more formal and informal collaboration between these organizations.*

The next observation was:

> *Radiation for deep spaceflight is a serious problem. It is not likely we can mitigate all (many?) of the risks adequately to meet current radiation health standards. Some level of risk must be accepted (mission risk and long term health risk). It is not clear how accurately we can define both types of risk based on our current baseline heliospheric observations and knowledge of human biology. There may be other means of informing the radiation problem (stellar observations, geologic record, modeling) and human biology.*

Some of the other comments/observations were:

- Radiation needs to be put into context with all of the risks associated with a mission to Mars. We need to be careful that the focus on this doesn't draw resources away from management of other risks.
- How does current engineering fit into mitigation strategy?
- Do we need shield tests in deep space?
- What about surface activities? Habitats? Suits? Vehicles?

The group discussed what "basic message" the joint Committees wanted to send. There was consensus to encourage NASA to put a long-term, medical care plan in place to provide more targeted medical care. In addition, it was felt that there should be more work on shielding. Dr. Longnecker noted that his research advisory group made a recommendation some time ago that all astronauts participate in the longitudinal study.

Dr. McComas suggested using the first paragraph as introduction or finding, then cite a list of things as a few examples of further actions. Mr. Bowersox noted that the overall reaction is that NASA is doing a good job now, and the Committees could offer some suggestions for improvement.

There was general consensus on the finding and recommendation. The Committees agreed to have Dr. Robinson perform some additional editing on the draft so that it could be discussed at the individual Committee meetings in the afternoon.

The Joint HEO/SC Committees meeting was adjourned at 10:00 a.m.

HEO COMMITTEE MEETING

In the afternoon, the HEO Committee reconvened its separate meeting. Dr. Siegel called the meeting to order and made the appropriate FACA announcements.

International Space Station Status

Ms. Robyn Gatens, Acting Deputy Director of ISS, reviewed the ISS goals and what they are doing in exploration and commercial market development. In response to question from Dr. Longnecker, she noted that the docking system will have an international docking adaptor.

NASA has set up System Maturation Teams that have identified gaps for future missions that can be enabled through ISS. They are working to prioritize and plan for ISS demonstrations. Ms. Gatens highlighted some of the near-term planned demonstrations. In response to a question on what is unique about the deployable solar array, Ms. Gatens could not specifically answer the question, but indicated she could get back to the Committee on that. She stated that the uniqueness involves how it is deployed.

Ms. Gatens showed a chart visually depicting the Exploration Technology Fly Off Plan. Mr. Bowersox noted that one or two quarters ahead, the Committee would like to dive deeper into some of these things. Ms. Gatens noted that the schedule to get everything done bumps up against the Station end-of-life (2024) and is funding-dependent.

Ms. Gatens reported on some summary finding highlights from the LEO Commercialization Strategic Planning Workshop. Coming out of the Workshop, there was a recommendation for NASA to develop a strategic plan for commercialization. The complete workshop summary is available at http://www.nasa.gov/directorates/heo/LEO_commercializaiton.

The Program has completed the first layer of the strategic plan—the Vision: "Sustained economic activity in LEO enabled by human space flight, driven by private and public investments creating value and benefitting Earth through commercial supply and public and private demand." Four goals have been outlined, for both today and into the future. Much of this is in concert with what CASIS and the ISS Program are doing, and the plan builds upon those initiatives.

Ms. Gatens briefed the Committee on the ISS orbital status. The next event is SpaceX-6. The one-year crew is now on-orbit. Three crew will be coming down on Soyuz 41S, and the next crew will be launched on Soyuz 43S in May. Later in the summer, there will be a number of visiting vehicles. Ms. Gatens also reviewed the highlights from increments 43 and 44. She noted that a considerable amount of reconfiguration is occurring. The "big picture" goal of the reconfiguration is to establish two docking ports and two berthing ports on the ISS U.S. Orbiting Segment (USOS) to support both crew and cargo vehicles.

Ms. Gatens showed the traditional status chart on consumables. ISS is in good shape and will be in even better shape with next SpaceX flight. Mr. Bowersox noted that the chart does not show a lot of food on SpaceX-6 and questioned how the USOS has a later "capability" date. Ms. Gatens clarified that the USOS date presumes food only for USOS.

Ms. Gatens provided a brief update on the pertinent ISS vehicle issues and what is being done to address them. She highlighted an approach that NASA is taking to "Revolutionize ISS for Science and Exploration" (RISE). RISE will better enable process focus. Mr. Gerstenmaier added that RISE has had some real success and that Ms. Gatens could provide the Committee with some specific examples.

Ms. Gatens reviewed the status of the SpaceX-6 mission that is scheduled for launch on April 13; SpaceX-7 will launch in June and will carry the international docking adaptor and other cargo.

The Orbital (Orb)-3 anomaly investigation is still ongoing. A high-level summary of the NASA-led review was provided to Orbital last week; however, they have not yet concluded their activity. Ms. Gatens reviewed Orbital's return-to-flight plan. Orb-4 is currently planned to launch around the end of the year.

Evaluation is underway for the next cargo resupply contract (CRS-2). Selection is expected in June 2015. (Since the selection has been delayed until September.) The next contract will carry the program through ISS end-of-life.

In response to question from Mr. Sieck, Mr. Gerstenmaier indicated that his team would provide more information on the ISS anomalies and what NASA is doing to close them out. There are fewer failures than predicted, but they are consuming valuable crew time. Dr. Longnecker inquired about the consequences of these anomalies. Mr. Gerstenmaier indicated that NASA is continuing to learn. The Program expected much more reliability in some of the systems than has been seen. It has taken time for some of the problems to show up. For many systems, long runtime is needed to understand all of the risks and consequences. From the overall roadmap perspective, NASA must be making decisions now to push some of the new technology in order to get the necessary runtime on it. Mr. Voss suggested a presentation on ISS reliability at a future meeting. In response to a question from Mr. Lopez-Alegria regarding life support equipment, Ms. Gatens indicated that pumps are probably the biggest current issue. There is a new urine pump candidate that looks promising. The Program has a lot of data that it can show the Committee at future meetings.

Dr. Tara Ruttley, Associate Program Scientist on ISS, provided an update on utilization. She showed an overview chart on the state of the increment 43-44 crew time. She noted that they could manifest twice the research if they just had the crew time for it. There is a fluctuation on utilization through time, depending on available crew and number of EVAs. As noted earlier, the biggest ISS reconfiguration since assembly will occur this year. This will require a substantial amount of crew time. In response to a question from Mr. Lopez-Alegria, she noted that when ISS goes from 3 to 4 crew, utilization will get another 35 hours per week over what they have now. Mr. Gerstenmaier confirmed that the research time will double.

Dr. Ruttley provided some ISS occupancy highlights. Internal occupancy is 81 percent, and crew time is heavily oversubscribed. External occupancy is going up fast—it currently includes instruments for astrophysics and Earth science. By 2017, only two sites will still be available.

Mr. Holloway noted that they have improved utilization quantity a great deal, but queried if they are meeting NASA's expectations in terms of quality and spectrum of activity. Dr. Ruttley responded that they are, and gave an example of how CASIS is branching across the pharmaceutical area. About 37 of the 50 CASIS experiments are new for Expedition 43/44. In response to a question, Dr. Ruttley indicated that she could not speak to the split between those receiving CASIS funding and those "paying their own way."

Dr. Ruttley noted the research statistics through February. The number of investigations for increment 43/44 is 356. For Expedition 0 through increment 40, there have been 1,765 individual investigations. Dr. Ruttley showed the breakdown of investigations by discipline. She highlighted examples of model organisms on ISS in 2014-2015. Studying model organisms in space contributes to understanding basic processes that can also be applied on Earth.

Dr. Ruttley discussed the first flight of Rodent Research-1. Mr. Gerstenmaier added that NASA is consciously "seeding the market" to encourage commercial use. In response to a question, Dr. Ruttley stated that from the pharmaceutical perspective, the commercial sponsor is interested in studying muscle atrophy to help guide some of their pharmaceutical development. Dr. Ruttley reminded the Committee about the ISS one-year mission—the year-in-space study and the twin study. She noted that it was the first time NASA has been on the cover of *Time* magazine since the Gemini program.

Dr. Ruttley showed a reference chart that depicted the research complement for increment 43/44 and noted that all of the National Lab is included. She cited a couple of examples of advancements enabled by ISS research:
(1) Microencapsulation Electrostatic Processing System (MEPS) flown on STS-95 (1998) and ISS Expedition 5 (2002), where the unique behavior of fluids in microgravity led to improvements in microcapsule development and

manufacturing of commercial-scale quantities of the desirable microcapsules; and (2) Japanese scientists crystallized a protein (H-PGDS) involved in the progression of Duchenne Muscular Dystrophy to provide insight on how to improve the inhibitor in patients and improve quality of life. Researchers are studying the effects of the improved inhibitor. She also noted that "Benefits for Humanity, 2nd Edition" is coming out in July 2015. It will give examples of innovative science, technology and economic development of space. She referred the Committee to http://www.nasa.gov/stationbenefits.

Commercial Crew Program Status

Before Mr. Phil McAlister started his briefing, Mr. Bowersox stated that at some point, perhaps at the next meeting, the Committee would like to see more on the technical design details of the proposed vehicles.

Mr. McAlister discussed the status of the CCP Space Act Agreement (SAA) and the status of the CCtCap, provided an overview of the CCP budget, and discussed the status of the CCP Independent Review. This year will see a lot of reviews along with a couple of important tests.

Blue Origin is continuing with development of its space vehicle. Under unfunded SAA, NASA is participating and facilitating the work toward the milestones. Sierra Nevada Corporation's (SNC's) SAA is also still active. SNC has one funded milestone left and an unfunded milestone has been added. The SpaceX Commercial Crew Integrated Capability (CCiCap) agreement is still active and has been extended to December 2015.

Mr. McAlister reviewed the CCtCap contract objectives to complete the development and certify the systems. In response to a question from Dr. Condon, he affirmed that each contractor will transport four crew to ISS. The CCtCap contract includes three Contract Line Items (CLINs): CLIN 001, certification; CLIN 002, post certification missions; and CLIN 003, special studies. All of the CLIN 001 milestones are fixed price. If the contractors make it through certification, they are guaranteed two missions each. The maximum number of missions is six each. If NASA exercises all the missions, the transportation service could go into 2023. The missions are pre-negotiated (fixed price), but the prices vary from flight to flight. CLIN 003, special studies, is for NASA to pursue work that it thinks it needs to reduce risk or perform additional tests or analyses. CLIN 003 will be under Indefinite Delivery/Indefinite Quantity (IDIQ) task orders. In response to a question from Mr. Sieck on whether NASA can invoke more oversight through the special studies, Mr. McAlister indicated that NASA could not specifically do this, but it can order activities that would provide a higher confidence level, e.g., to expand the test parameters to understand the environment. CLIN 003 is not intended to be used to add additional requirements, and NASA must be very careful and judicious in applying any new requirements. In response to a question from Mr. Bowersox regarding circumstances under which NASA would have to go back into negotiations, Mr. McAlister agreed that lack of funding from Congress could require negotiations if contractors request equitable adjustment for funding delays. Schedule is part of the contract. Every milestone has entrance and exit criteria. Mr. McAlister emphasized that there is not a lot of funding flexibility.

Mr. McAlister discussed the flight test programs that were proposed. Boeing has a pad abort test in 2017, an uncrewed orbital flight test to ISS in 2017, and a crewed flight test to ISS in 2017. SpaceX has a pad abort test this month (under CCiCap), an in-flight abort test in September 2015 (also under CCiCap), an uncrewed ISS flight in 2016, and a flight to ISS with crew in 2017. The acceptability of these tests will be determined by NASA.

Mr. McAlister briefly discussed the Boeing concept: a CST-100 crew capsule spacecraft, launched using United Launch Alliance's (ULA's) Atlas 5 launch vehicle, and landed using parachute and airbag systems for land landings or contingency water landings. Boeing plans to launch from Launch Complex (LC)-41 (the current Atlas 5 launch pad) at Cape Canaveral Air Force Station. It has met its first four milestones under the contract and has kicked off all the subcontracts (a big accomplishment for Boeing). The Delta CDR was held in March, and NASA is still evaluating the data. Multiple Technical Interchange Meetings (TIMs) have been held with NASA to provide insight. In response to a question from Mr. Lopez-Alegria, Mr. McAlister noted that the key focus of the Certification Baseline Review (CBR) was enabling NASA to understand more precisely where Boeing is. He presented a chart showing the Boeing CCtCap development milestones. He indicated that some "flux" in the chart is expected, but it

all should come together in the end. NASA is putting together some other ways to show progress. CLIN 001 goes to FY18. The other CLINs can go all the way out to 2023. In response to a comment, Mr. McAlister replied that adding more flights would be a more complex matter.

Space X is currently planning on a water landing, but they have a future upgrade to a soft land landing. They plan to launch from LC-39A (the former Shuttle pad). SpaceX met its CBR; there is good communication and work is in full flow. NASA has access for the people who need it. Mr. McAlister showed the Space X milestones, which are fewer than Boeing, because the CCtCap milestones are based on the company proposal.

Mr. McAlister discussed the CCP budget. The CCP is funded at $805 M for FY15. FY16 is a fairly robust request--$1.2 B. This is the "high-water mark" for CCP. It will be critical to enable NASA and the contractors to meet the goal of 2017.

Mr. McAlister highlighted several independent reviews by the Office of Inspector General (OIG), the General Accounting Office (GAO), and the Aerospace Safety Advisory Panel (ASAP), which is briefed quarterly and as needed. Ongoing activities include a Standing Review Board (SRB), and quarterly reports required by the Appropriations Act. Mr. McAlister expanded on the SRB activity and equivalent Key Decision Points (eKDPs). The SRB's role is to evaluate how well NASA is doing on what it is required to do. The eKDP I establishes the Agency Baseline Commitment for CCP, which will include a baseline plan, cost through Design, Development, Test and Evaluation (DDT&E), and the schedule for certification. In response to a question from Dr. Condon about using the commercial transportation capability beyond this current contract, Mr. McAlister replied that if the ISS is still operational after 2023, there would have to be another contract. NASA has not established the acquisition strategy, but he would expect a full and open competition. It is too early to say if more than one provider would continue. NASA has a LEO commercialization team that is looking at the transition process from a government-oriented activity in LEO to a commercial activity. Mr. McAlister indicated that he did not foresee everything being "done" by 2024. One of the reasons why NASA is doing unfunded SAAs is that it anticipates there will be another competition. The CCtCap contract has a "new entrant" clause that provides NASA with an ability to look at other providers.

Asteroid Redirect Mission

Dr. Michele Gates, ARM Program Director, discussed the work that has been done since the last meeting – the feasibility analysis for the crewed mission and its applicability as well as for the robotic mission. The Evolvable Mars Campaign (EMC) is the horizon architecture study. Dr. Gates highlighted the four key aspects of ARM: moving large objects through interplanetary space using Solar Electric Propulsion (SEP); integrated crewed/robotic vehicle operations in lunar distant retrograde orbit (DRO), lean implementation, and integration of robotic mission and human space flight capabilities. She noted the ARM contributions to future deep space missions. The mission concept selected also provides an opportunity for demonstration of planetary deflection techniques that will inform future planetary defense approaches. Dr. Gates discussed the SEP module extensibility for Mars and reviewed the 2014 ARM accomplishments. She discussed in more detail the Orion Modified Advanced Crew Escape Suit (MACES) testing at JSC.

Dr. Gates described some of the robotic mission concepts and trades that were done last year: two options for asteroid capture, rendezvous and proximity operations sensors, adapting commercial spacecraft for the Asteroid Redirect Vehicle, and future partnership opportunities for secondary payloads and the Asteroid Redirect Crewed Mission (ARCM).

The purpose of the Mission Concept Review (MCR) for the Asteroid Redirect Robotic Mission (ARRM) was a detailed review of options as well as the assessment of programmatic risks. Dr. Gates presented the success criteria for the MCR. Dr. Condon observed that, in looking at all the criteria, NASA is still counting on what is a fairly random event before everything else can be triggered, i.e., the identification of a target that meets all the criteria. He posed the question: How do you integrate these functions with identification of the probable targets? Dr. Gates responded that currently, there are three "valid" targets. This was one of the accomplishments of 2014. The three

valid targets will have had either precursor missions or comprehensive radar opportunity from which to infer the existence of boulders. There is a list of many candidate targets as well. NASA will continue to look for targets up to a year prior to launch. Target selection is planned to be one year before launch.

Dr. Gates reviewed the ARM highlights and the concept of operations. She provided some additional detail on the ARRM capture phase. The result of the MCR was selection of capture option B, launch date in December 2020, cost cap of $1.25 B (not including investment in launch vehicle and mission operations), codifying the internal and external dependencies, and defining the implementation approach. The level 1 requirements are in draft and still being worked. Dr. Gates described the ARRM baseline concept, the crewed mission accommodations (docking and EVA), and the integrated test flow. In response to a question from Mr. Lopez-Alegria, she noted that through EVA the crew will select, extract, contain, and return the samples. Dr. Gates showed the ARRM concept development summary schedule through December 2020.

Mr. Bowersox thanked Dr. Gates for her presentation, which provided the Committee with a considerable amount of information on the ARM. He observed that after its mission, the ARM bus could be free for other uses, such as science missions.

Pioneering Space - The Evolvable Mars Campaign

Mr. Jason Crusan introduced his presentation with the "Journey to Mars" graphic that communicates the synergy among science, exploration, and technology and a journey that moves from Earth Reliant to Proving Ground to Earth Independent phases. The Proving Ground will be used to advance capabilities before heading into the Earth Independent phase of missions. At this point Mr. Greg Williams picked up on the presentation. He clarified three terms and their proper association: Journey to Mars, Pioneering Space, and the Evolvable Mars Campaign (EMC). The "Journey to Mars" is the Agency-level theme to fulfill the commitment to the White House and Congress to get us where we want to go in the long-term. "Pioneering Space" is the idea that this journey will take a long time and is reflective of the idea that we don't want to just go to Mars, "plant the flag," and then return to LEO for decades. It is the idea to construct an endeavor that is long-term and sustainable. The EMC is the set of technical studies being conducted to define how we will pioneer space in the journey to Mars. The evolving architecture will allow us to take advantage of new technologies and partnerships, while not having to make today the decisions that should be made seven years from now. NASA is going to produce a document "Pioneering Space: Progress and Next Steps on the Journey to Mars." It will be an integrated, Agency-level document that articulates NASA top-level exploration strategy encompassing robotics, human operations, and technology developments of the near and far-term. The target audiences are internal, non-technical policy and decision makers, international space agencies, and other special groups.

Mr. Williams indicated that he expects the document to be about 32 to 36 pages long. He reviewed the outline and overall flow of the document. Mr. Bowersox confirmed that this document will be at a higher level than a design architecture document. He asked when people can expect to see a more detailed document. Mr. Gerstenmaier indicated that it would probably be a couple more years before there would be a definitive document for other than the near-term sequence. He indicated that they want to get a lot of questions answered and get a more solid framework before they produce the definitive document, e.g., how many launches it will take to get to Mars. What is wanted is an architecture that is sustainable and pushes exploration into the solar system.

In response to a question from Ms. Bartell on what is different about this plan, Mr. Gerstenmaier noted that one of the big changes is SEP and the ability to take cargo and crew on different timetables. The other piece that is different is splitting cargo and crew and pre-positioning cargo. NASA has not taken a single mission approach but is looking at how to build a sustainable architecture that will leave pieces behind that can be used in the future. They are also stepping back and looking at the logistics problems before homing into a solution. Ms. Bartell agreed that certain things do sound different; it is important that NASA articulate the story in terms of why this is different—not just more trade studies. Mr. Gerstenmaier explained that NASA has picked the trade studies it is going to do;

they need to start getting runtimes on systems, e.g., life support systems, today. Mr. Williams emphasized that what is different is a sustainable approach versus one that accomplishes something and then falls back.

Mr. Crusan continued the briefing. A common perception of human space flight has been Apollo-class missions—going there for short duration with a single goal—and that's what they are trying to change. Pioneering Space pulls on the specific quote from President Obama's speech in April 2010, in which he stated that, "…Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite…" The specific purpose of going to Mars is now noted in NASA's Strategic Plan (Objective 1.1). Mr. Crusan showed the strategic principles for sustainable exploration that were presented to the Committee at its last meeting. The EMC includes a series of analyses in the Earth Reliant (low-Earth orbit), Proving Ground (cis-lunar) and Earth Independent (Mars and beyond) trade spaces. In response to a question, Mr. Crusan indicated that none of the decisions on cis-lunar space would preclude landing on the Moon, if that were to be a decision in the future. Mr. Gerstenmaier opined that we don't gain that much for the cost to go to the surface of the Moon. However, if we do, this architecture would be open to reusable activities there.

Mr. Crusan reviewed the Proving Ground objectives that will enable human missions to Mars. It will validate systems and capabilities through analyses and flights as well as conduct EVAs in deep space and integrated human and robotic mission operations. He highlighted the major results to date. He showed a graphic that has been updated to depict the Earth and Moon gravity wells and the DRO. It showed the highly stable region between the Earth and Moon. Mr. Gerstenmaier added that NASA is using time as a dimension in getting humans back to the Earth's surface. "Home" from Mars is the cis-lunar space around the Moon, not the surface of the Earth. In response to a question from Mr. Bowersox on how sensitive this orbit is to targeting or timing errors, he indicated that it is not that sensitive—it is in the order of days. Mr. Gerstenmaier noted that these are some of the trades that NASA wants to do. All of these ideas look promising, but until you get into the analysis details, you don't really know. This is why it is important that Orion goes to DRO on EM-1.

Mr. Crusan reviewed the SLS Block 1B and mission element concepts that are under study. Eight-meter and ten-meter fairings are mission concepts. The ARM is a stepping-stone to higher power SEP needed to support human missions to Mars. He compared the 300 kW SEP with the Space Shuttle Main Engine (SSME). It is important to look at energy output over time to understand how the SEP model scales up to what is needed.

Mr. Crusan reviewed the EMC ground rules and constraints and highlighted the FY2015 EMC questions/work groups. He discussed some of these in greater detail: phased implementation of the in-situ resource utilization (ISRU) strategy, Mars site selection, SEP module extensibility for Mars, largest payload element and options for lander size, and habitation system extensibility. In addition to efforts in-house, NASA has been engaging with industry.

Mr. Crusan presented an overview of the NextSTEP BAA. NASA solicited three critical areas for technology maturation: advanced propulsions systems, habitation systems, and small satellite missions. Twelve proposals were selected to enter into fixed-price contracts.

NASA put together a series of System Maturation Teams to identify performance parameters needed for each Capability Driven Framework (CDF) mission class. Mr. Crusan presented a chart that he called the "decoding ring:" the NASA technology roadmaps and investment plan. It is intended to show that there is a method to get to project or mission implementation.

Committee Discussion and Findings/Recommendations

The Committee discussed Dr. Robinson's updated draft on a Joint HEO/Science recommendation entitled "Enhanced Radiation Risk Assessment." Mr. Bowersox noted that the Science Committee has not seen as much about the engineering strategies as the HEO Committee has. With respect to the recommendation itself—

encouraging initiating a long-term astronaut health monitoring and medical care program to mitigate long-duration exposure health consequences to astronauts and build a baseline for future long-term engineering decisions—Mr. Bowersox suggested that some "why" is needed to first introduce the recommendation. With respect to citing other means of investigating the full extent of the radiation problem, Dr. Condon was concerned that as written, it was open-ended and needed to be reworded. Mr. Bowersox agreed that it was vague and needed to be "tightened up" to be as specific as possible. The Committee agreed that the language of the recommendation needed to be worked. Dr. Longnecker made the generic point that deep space experiments are not the only experiments that need to be done. If "fields" are going to be listed, some of those fields should be HEO-centric, not just helio-centric.

Mr. Bowersox indicated that he would communicate these comments back to the Science Committee, and he asked Mr. Chiao to do some work on a rewrite.

The Committee took a break in its discussion of findings and recommendations to conduct the public comment period. There were no public comments, and the Committee discussion resumed.

The Committee reviewed its previous recommendations, findings, and topics still under discussion. Mr. Bowersox noted that the Optimal SLS flight rate recommendation was forwarded to and accepted by NASA. The Committee also had a recommendation on affordable program management that was held over to this meeting.
The previous finding on expanding the NASA research community was forwarded to the HEOMD Assohte Administrator.

Other topics under discussion were:

- HEOMD and SMD cooperative efforts;
- NASA management processes/potential for cost reduction;
- communication plans for the Exploration Strategy (Dr. Condon noted that this was particularly aimed at getting the public engaged in a mission to Mars);
- ways to add content or accelerate exploration plans; and
- technology development, specifically an interest in propulsion activities.

Mr. Bowersox showed the proposed NAC recommendation on "Focus on Affordable Program Management." The actual recommendation was fairly modest – take a look at the way tailoring is done and look at standing review groups. When presented at the NAC, the Council members thought that this was such an important recommendation that it should hear from the Chief Engineer's office before proceeding. More work will be done on the recommendation at the NAC level. Mr. Bowersox asked the Committee if anything in the recommendation needed to be reworked. Mr. Holloway opined that NASA needs an effort to "get the bureaucracy under control." Mr. Bowersox indicated that he would relay those comments to the NAC. What the Committee was worried about was that NASA would kick off a big study that wouldn't result in any reduction. It was noted that the Chief Engineer presentation would be a general presentation on 7120. Ms. Bartell observed that there is another large document that explains 7120. Mr. Bowersox added that the problem is that there are a lot of "stakeholders" that have to get involved in moving things (such as tailoring) forward. With regard to the Independent Review Team (IRT), Ms. Bartell noted that the question is not just the IRT itself; it is that the Center Directors' review people have been put back in the loop.

Mr. Bowersox discussed the Committee's future work plans:
Summer 2015: Standard repeating topics and special topics: commercial opportunities in exploration plans, communication strategy for exploration, and joint meeting with the Technology Committee to discuss advanced propulsion work (hydrocarbon engine).

Fall/Winter 2015: Standard repeating topics plus special topics: international participation in future human exploration and ISS uses for exploration development. Mr. Bowersox noted that Mr. Holloway had suggested that it would be good to get with some of the JSC people at the Fall/Winter meeting.

The Committee revisited the "Communication Plans for Exploration Strategy" topic. Dr. Condon said that his underlying assumption is that if this exploration approach is ever going to be funded, it will need popular support. The way to do that is to communicate to the public and Congress what it is NASA is going to do, why it is going to do it, and how it will benefit all mankind.

Mr. Bowersox noted that the Science Committee builds support for programs and gets the broader community involved through its Subcommittees. However, rather than expand the HEO Committee's subcommittee structure, the Committee itself will work through it.

At this time, the Committee discussed Dr. Chiao's edits on the recommendation on Enhanced Radiation Risk Assessment. The resulting draft recommendation was as follows:

> *We recommend continuing long-term astronaut health monitoring and initiating a medical care program to mitigate long duration exposure health consequences to astronauts, and build a baseline for future long term mitigations. Thus, we encourage NASA to consider additional related fields to be investigated. There may be other means of investigating the full extent of the radiation problem (for example, stellar observations, geologic record, modeling, understanding of the heliospheric environment) not currently under study.*
>
> *We encourage NASA to openly acknowledge radiation risks while they are continually being mitigated through improved knowledge and technology.*

The Committee discussed how to make the latter part of the recommendation useful. Mr. Holloway suggested focusing on what the Committee wants NASA to do. Overall, the HEO Committee felt that NASA was being open. Mr. Bowersox agreed to modify the statement based on the Committee discussions (i.e., they are doing good work, continue on the path that they are on) and move it from the recommendation to the background paragraph as a finding. He indicated that he would talk with Dr. McComas about the modifications.

Dr. Longnecker suggested changing the last sentence in the background statement. Mr. Bowersox agreed that the two Committees would ask for a future briefing on engineering aspects rather than making it a recommendation.

Mr. Lopez-Alegria commented that if the recommendation is specific about the environment aspects, it should be specific about the medical aspects. He proposed that the statement include something about biological effects on humans as well as the environment.

Before adjourning, Mr. Bowersox invited closing comments from the Committee. Dr. Longnecker commented that this was one of the best Committee meetings that has been held. The work that was done within the HEO Committee and with Science Committee was extremely helpful. Mr. Bowersox suggested that for the future, he might want to consider having the Research Subcommittee hear a lot of the information. Dr. Longnecker noted that the Research Subcommittee may need to add someone from the radiation community to its membership. Mr. Holloway stated that he now understands Mr. Gerstenmaier's rationale for why he is doing what he is doing. It became clear at this meeting, and it makes a compelling story for why he is on the right track. Mr. Bowersox observed that NASA could lay out a plan today for how to get to Mars; however, that plan would be so sensitive to assumptions, it could be way off on hardware and budget estimates. By waiting a few years, there could be a lot more fidelity in the plan. Mr. Holloway agreed that we are not "smart enough" now to make a decision; we might not consider the best plan unless we consider what the trades and options are. Mr. Levin indicated that he took some comfort as well in Mr. Gerstenmaier's statement that sooner or later, we must have deadlines on when decisions have to be made; otherwise, we will not move forward. Mr. Lopez-Alegria observed that scientists and operators think very differently. It was productive to hear how each other thinks. However, that process tends to take a long time. He recommended that the Committee continue this activity, but be mindful of the time it is spending. Ms. Bartell agreed with Mr. Lopez-Alegria's statement that scientists and operators think about things differently; however, it was very beneficial to have the two in the same room and discuss a topic of importance to

both. Dr. Condon agreed that it had been a very instructive and productive meeting. Mr. Bowersox thanked everyone for the time that was invested.

Dr. Siegel reminded everyone that the next meeting would be the last week of July at the Jet Propulsion Laboratory (JPL), Pasadena, CA. The meeting was adjourned at 4:55 p.m.

NASA ADVISORY COUNCIL
Human Exploration and Operations Committee Meeting
NASA Headquarters
300 E Street SW, MIC 3A & MIC 5A
Washington, DC 20546

April 7-8, 2015

AGENDA

Tuesday, April 7

NAC HEO COMMITTEE PUBLIC MEETING IN MIC 5A

10:00 - 10:02 am	Call to Order, Welcome & Opening Remarks	Dr. Siegel & Mr. Bowersox
10:02 – 11:00	Status of the Human Exploration and Operations Mission Directorate	Mr. William Gerstenmaier
11:00 – Noon	FY16 President's Budget Request	Mr. Gerstenmaier & Ms. Toni Mumford
Noon – 1:00 pm	***LUNCH***	

NAC HUMAN EXPLORATION & OPERATIONS COMMITTEE / NAC SCIENCE COMMITTEE
JOINT MEETING IN MIC 3A

1:00 – 1:02 pm	Call to Order & Welcome	Dr. Bette Siegel & Ms. Denning
1:02 – 1:10	Opening Remarks & Member Introductions	Mr. Kenneth Bowersox Dr. David McComas
1:10 – 3:00	Space Radiation Discussion	Dr. Steve Davison, Dr. Chris St. Cyr, Dr. Allan Tylka, Dr. Tony Slaba, Dr. Nathan Schwadron, Dr. Veronica Bindi, Dr. Eddie Semones, Dr. Lisa Simonsen, Dr. David Liskowsky
3:00 – 3:15	BREAK	
3:15 – 5:25	Space Radiation and Discussion	
5:25 – 5:30	Public Comments	
5:30	ADJOURN	

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Wednesday, April 8

NAC HUMAN EXPLORATION & OPERATIONS COMMITTEE / NAC SCIENCE COMMITTEE
JOINT MEETING CONTINUES IN MIC 3A

8:30 – 8:32	Call to Order, Welcome & Opening Remarks	Mr. Bowersox & Dr. McComas Dr. Siegel & Ms. Denning
8:32 – 10:00	Joint HEOC/SC Discussion	
10:00	*ADJOURN JOINT MEETING*	
10:00 – 10:30	Return to MIC 5A and Break	
10:30 – 10:35	Call to Order & Opening Remarks	Mr. Bowersox & Dr. Siegel
10:35 – 11:35	Commercial Crew Program Status	Mr. Phil McAlister
11:35 – 12:35 pm	***LUNCH***	
12:35 – 1:35	Status of International Space Station	Ms. Robyn Gatens & Dr. Tara Rutley
1:35 – 2:35	Asteroid Redirect Mission	Dr. Michele Gates
2:35 – 3:35	Evolvable Mars Campaign	Mr. Greg Williams & Mr. Jason Crusan
3:35	***Break***	
3:50 – 3:55	Public Comments	
3:55 – 5:25	Discussion and Findings/Recommendations	
5:25 – 5:30	Next Steps and Closing Remarks	Mr. Bowersox
5:30	***ADJOURN***	

Human Exploration and Operations Committee Membership
April 2015

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
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. Richard Malow	Distinguished Advisor at the Association of University for Research in Astronomy (AURA)
Mr. James Odom	Former NASA Associate Administrator for Space Station Freedom
Mr. Bob Sieck	Former Space Shuttle Launch Director
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 Headquarters
Washington, DC

April 7-8, 2015

MEETING ATTENDEES

HEO Committee Members:

Bowersox, Ken, *Chair*	U.S. Navy *(Ret.)*
Siegel, Bette, *Executive Secretary*	NASA Headquarters
Bartell, Shannon	Aerospace Consultant
Chiao, Leroy	Aerospace Consultant
Condon, Stephen "Pat"	Aerospace Consultant
Holloway, Tommy	Aerospace Consultant
Levin, Lon	SkySeven Ventures
Longnecker, David	AAMC
Lopez-Alegria, Michael	Commercial Spaceflight Federation
Sieck, Bob	Aerospace Consultant
Voss, James	University of Colorado, Boulder

NASA Attendees:

Adde, Barbara	NASA Headquarters
Bailey, Lora	NASA/JSC
Broadwell, Marguerite	NASA Headquarters
Bussey, Ben	NASA Headquarters
Carpenter, Brad	NASA Headquarters
Craig, Doug	NASA Headquarters
Crusan, Jason	NASA Headquarters
Davis, Jeffrey	NASA/JSC
Davis, Rick	NASA Headquarters
Edgington, Stacey	NASA Headquarters
Gatens, Robyn	NASA Headquarters
Gates, Michele	NASA Headquarters
Gerstenmaier, William	NASA Headquarters
Guidi, John	NASA Headquarters
Irving, Rick	NASA Headquarters
Kamm, Shari	NASA Headquarters
Lewis, Ruthan	NASA/GSFC
Mahoney, Erin	NASA Headquarters
Marinaccio, Louisa	NASA Headquarters
Mauk, Robin	NASA/GSFC
McAlister, Phil	NASA Headquarters
Nilly, Janet	NASA Headquarters
Pagel, Lee	NASA Headquarters
Paloski, Bill	NASA/JSC

Robinson, Shawanda	NASA Headquarters
Roman, Monsi	NASA Headquarters
Rutley, Tara	NASA Headquarters
Williams, Greg	NASA Headquarters

Other Attendees:

Bindi, Veronica	University of Hawaii
Damphousse, Paul	General Astroautics, LLC
Dittner, Mary Lynne	CASIS
Frankel, Paula	P B Frankel, LLC
Gillin, Joe	*[not affiliated]*
Karanian, Linda	Aerojet Rocketdyne
Stout, Jared	House Subcommittee on Science & Technology

NAC HEO Committee WebEx Attendees:

Atkinson, Loretta
Becker, Karl
Berger, Eric
Bingham, Jeff
Branscome, Darrell
Bryant, Devin
Campbell, Paul
Clark, Stephen
Day, Dwayne
Drake, Bret
Dreler, Casey
Foust, Jeff
Gerrisk, Harold
Gilbert, Chris
Hambleton, Kathryn
Lembeck, Michael
Manning, Josh
Morring, Frank
Passmore, Richard
Proudfoot, Robert
Rummel, John
Schierholz, Stephanie
Smith, Marcia
Sulkowsky, Amy
Svitak, Ann
Thomas, Andrew
Tolomeo, Raymond
Zimmerman, James
Harwood, William

NAC HEO Committee Telecon Attendees:

Buzz	Aldrin	Retired Astronaut
Natalia	Alexandrov	NASA Langley
Gale	Allen	NASA HQ
Loretta	Atkinson	NASA Inspector General's Office
William	Atwell	Retired Boeing
David	Balajthy	NASA OIG
Karl	Becker	NASA HEO
Eric	Berger	Houston Chronicle
Jeff	Bingham	Retired NASA
Darrell	Branscome	DRB Associates Corp
Marguerite	Broadwell	NASA
Devin	Bryant	NASA
Elizabeth	Buchen	Spaceworks
Paul	Campbell	Lockheed Martin
Steven	Clarke	Space Flight Now
Al	Condes	NASA
Keith	Cowing	Tax Payer
Nicholas	Cummings	US Senate
Steve	Davidson	NASA
Dwayne	Day	NRC
Bret	Drake	NASA JSC
Casey	Dreier	Planetary Society
Susan	Edgington	NASA
Kevin	Fagedes	NASA OIG
Andrew	Follett	US Council of Representatives
Jeff	Foust	Space News
Robyn	Gatens	NASA HQ
Chris	Gilbert	VE Consult
Bill	Harwood	CBS News
Kyle	Herring	NASA
Shaowen	Hu	JSC
Janice	Huff	USRA
Richard	Irving	NASA
Andrew	Jordan	University of NH
Shari	Kamm	NASA Headquarters International Relations
Jacob	Keaton	NASA
Theodore	Krommiller	Law Office
Ruthan	Lewis	NASA
Erin	Mahoney	NASA
Josh	Manning	Senate
Robin	Mauk	Goddard Space Flight Center
David	Millman	

Sherry	Monk	NASA Langley
Frank	Morring	Aviation Week
Toni	Mumford	NASA Headquarters
Juergen	Nittner	Purdue University
Justin	Olivera	OMB
Richard	Passmoore	European Space Agency
Trent	Perrotto	NASA
Ianik	Plante	JSC
Robert	Proudfoot	NASA
Duane	Ratliff	Kentenio Applications
Christian	Rice	House Committee on Science
Richard	Rogers	Stellar Solutions
John	Rummel	East Carolina University
Tara	Ruttley	NASA
Chris	Sandrige	NASA
Stephanie	Schierholz	NASA
Donna	Shortz	NASA HQ
Sandra	Smalley	NASA HQ
Marcia	Smith	Spacepolicyonline.com
Jared	Stout	US House of Representatives
Amy	Svitak	Aviation Week Magazine
Marco	Tantarlini	Tech Institute for Space Studies
Andrew	Thomas	NASA Retiree
Raymond	Tolomeo	NASA
Charles	Werneth	NASA Langley
Ryan	Whitley	NASA
Michael	Winbeck	Logyx
James	Zimmerman	Retired NASA
Ann	Zulkosky	Lockheed Martin Space System

Joint NAC HEO Committee and Science Committee Attendees:

HEO Committee Members:

Bowersox, Ken, *Chair*	U.S. Navy *(Ret.)*
Siegel, Bette, *Executive Secretary*	NASA Headquarters
Bartell, Shannon	Aerospace Consultant
Chiao, Leroy	Aerospace Consultant
Condon, Stephen “Pat”	Aerospace Consultant
Holloway, Tommy	Aerospace Consultant
Levin, Lon	SkySeven Ventures
Longnecker, David	AAMC
Lopez-Alegria, Michael	Commercial Spaceflight Federation

Sieck, Bob	Aerospace Consultant
Voss, James	University of Colorado, Boulder

NAC Science Committee Members

David J. McComas, Southwest Research Institute, *Chair,* Science Committee
Scott Gaudi, Ohio State University, Chair, Astrophysics Subcommittee
James Green, University of Colorado at Boulder
Maura Hagan, NCAR, Chair, Heliophysics Subcommittee
Robert Kirshner, Harvard University
Janet Luhmann, UC Berkeley, Chair, Planetary Science Subcommittee *(via telecom)*
Robert Lindberg, Jr., University of Virginia, Chair, Planetary Protection Subcommittee
Harry McSween, University of Tennessee *(designee)*
Carlé Pieters, Brown University
Mark Robinson, Arizona State University
Steve Running, University of Montana, Chair, Earth Science Subcommittee
Harlan Spence, University of New Hampshire
David Spergel, Princeton University, *ex officio*
Elaine Denning, NASA Headquarters, *Executive Secretary*

NASA Attendees

Adler, Gabriel	NASA Headquarters
Allen, Gale	NASA Headquarters
Allen, Marc	NASA Headquarters
Arrivo, Therese	NASA Headquarter
Bailey, Lora	NASA JSC
Bambacus, Mara	NASA/GSFC
Beaty, Ralph	NASA Headquarters
Bernstein, Max	NASA Headquarters
Blatterly, Steve	NASA Headquarters
Carle Pieters	Brown University
Clarke, Steve	NASA Headquarters
Conley, Catherine	NASA Headquarters
Davis, Jeffrey	NASA Headquarters
Davison, Steve	NASA Headquarters
Freilich, Michael	NASA Headquarters
Fryberger, Teresa	NASA Headquarters
Gerstenmaier, William	NASA Headquarters
Green, James	NASA Headquarters
Grunsfeld, John	NASA Headquarters
Guhathakirti, Lika	NASA Headquarters
Hasan, Hashima	NASA Headquarters
Hayes, Jeffrey	NASA Headquarters
Hesford, Tyler	NASA Headquarters
Hertz, Paul	NASA Headquarters
Kaluzienski, Lou	NASA Headquarters
Killebrew, Jena	NASA Headquarters

Kirshner, Robert	Harvard University
Leaman, Robert	NASA Headquarters
Liskowsky, David	NASA Headquarters
Martin, Andrea	NASA Headquarters
Mauk, Robin	NASA GSFC
McIntyre, Joeseph	NASA Headquarters
Meyer, Michael	NASA Headquarters
Morrill, Jeff	NASA Headquarters
Newmark, Jeff	NASA Headquarters
Norbury, John	NASA Headquarters
Norvo-Gradai, Anne Marie	NASA Headquarters
Paloski, William	NASA JSC
Peterson, Bill	NASA Headquarters
Pellish, Jonathan	NASA Headquarters
Rausch, Diane	NASA Headquarters
Rivers, Christy	NASA Headquarters
Robinson, Shawanda	NASA Headquarters
Rumburg, Jenny	NASA Headquarters
Schneider, Victor	NASA Headquarters
Semones, Edward	NASA/JSC
Simonsen, Lisa	NASA/LaRC
Slaba, Tony	NASA/LaRC
Smith, Eric	NASA Headquarters
Smith, Erin	NASA Headquarters
Sambacus, Myra	NASA GSFC
Sambruna, Rita	NASA Headquarters
St. Cyr, Chris	NASA/GSFC
Stembler, Jeremy	NASA Headquarters
Stofan, Ellen	NASA Headquarters
Talahi, ElSayed	NASA Headquarters
Taylor, Ray	NASA Headquarters
Tylka, Allan	NASA/GSFC
Woods, Don	NASA Headquarters

Non-NASA Attendees

Avery, Susan	Woods Hole Oceanographic Institution
Bindi, Veronica	University of Hawaii
Gillin, Joe	
Keelor, Brad	British Embassy
Nittler, Larry	Carnegie Institute of Washington
Wilson, Ana	Zantech IT

Joint NAC HEO Committee and Science Committee Webex and Telecon Attendees

Natalia	Alexandrov	NASA Langley Research Ctr
Loretta	Atkinson	
Louis	Barbier	NASA HQ
Karl	Becker	NASA HEO
Richard	Binzel	MIT
Darrell	Branscome	DRB Associates Corp
Elizabeth	Buchen	SpaceWorks
Paul	Campbell	Lockhead Martin
Lisa	Carnell	NASA
Brad	Carpenter	Nasa
Mike	Ching	NASA
Stephen	Clark	Space Flight Now
Martha	Clowdsley	LRC
Al	Condes	NASA
Anne	Connor	Exelis
Keith	Cowing	Private Citizen
Michael	Crandall	Boeing
Nicholas	Cummings	US Senate
Steve	Davidson	NASA
Monty	DiBiasi	Southwest Research Institute
Cynthia	Dinwiddie	Southwest Research Institute
Marylynne	Dittmar	Dittmar Associates
Bret	Drake	NASA JSC
Conor	Duggan	
Robert	Easley	
Therese	Errigo	GSFC
Cornelis	Gehrels	
David	Hermreck	OSTP
Shaowen	Hu	Johnson Space Center
Janice	Huff	US RA
Richard	Irving	NASA
Brad	Johnson	Goddard
Andrew	Jordan	Univ of NH
Jason	Kalirai	Space Telescope
Dan	Kane	
Jennifer	Kearns	Nasa HQ
Yared	Kidane	Wyle
Myung-Hee	Kim	Nasa JSC
Theodore	Kronmiller	Law Office Theodore Kronmiller
Michael	Lembeck	Logyx
Dan	Leone	SpaceNews
Ruthan	Lewis	NASA
Mario	Livio	Space Telescope Science
Eric	Machmer	
Sashka	Mannion	NASA OIG
Robin	Mauk	Goddard Space Flight System
Brian	Mayeaux	JSC
Kevin	Miller	Strategic Space Solutions

Michael	Moloney	National Research Council
Sherry	Monk	NASA Langley
Frank	Morring	Aviation Week
Ryan	Norman	Langley Research
Daniel	Peters	NY Skies
Ianik	Plante	Johnson Space Center
Marc	Postman	Space Telescope Science Institute
Betsy	Pugel	NASA Headquarters
Julie	Rathbum	Monetary Science Institute PSI
Duane	Ratliff	Contineo
Christian	Rice	The House Committee on Science
Richard	Rogers	Stellar Solutions
John	Rummel	ECU
Tara	Ruttley	NASA
Stephanie	Schierholz	NASA
Mitch	Schulte	HQ
Zarana	Shavers	NASA
Marcia	Smith	Spacepolicyonline. com
Massimo	Spiabelli	Space Telescope Science Institute
Jared	Stout	US State House of Rep
Amy	Svitak	Aviation Magazine
George	Tahu	NASA Headquarters
Kim	Terrell	Katz International Management Solutions
Andrew	Thomas	NASA
Raymond	Tolomeo	NASA
John	Uri	JSC Human Research Program
Roland	Van Der Marel	Space Telescope Science Institute
Charles	Werneth	NASA Langley
Angela	Williams	Zantech it
Anna	Wilson	NASA
Jody	Wilson	University of NH

Human Exploration and Operations Committee
NASA Headquarters
Washington, DC

April 7-8, 2015

LIST OF PRESENTATION MATERIAL

1) Human Exploration and Operations [Gerstenmaier]
2) FY 2016 Budget Overview [Gerstenmaier]
3) Mars Mission and Space Radiation Risks Overview [Davison]
4) Institute of Medicine Report and OCHMO Implementation Plan [Liskowsky]
5) Space Radiation Environment [St. Cyr]
6) The Solar Energetic Particle (SEP) Radiation Hazard [Tylka]
7) Space Radiation Environment [Slaba]
8) Implications of the Worsening GCR Radiation Environment [Schwadron]
9) Emerging GCR Data from AMS-02 [Bindi]
10) Radiation Health Risk Projections [Semones]
11) Space Radiation Research and Technologies for Risk Mitigation [Simonsen]
12) International Space Station Status [Gatens]
13) Commercial Crew Program Status [McAlister]
14) Asteroid Redirect Mission Status [Gates]
15) Pioneering Space – the Evolvable Mars Campaign [Crusan]