National Aeronautics and Space Administration

HUMAN RESEARCH PROGRAM

2014 Fiscal Year Annual Report

*New **Ideas**. Meaningful **Research**. Promising **Results**.*

MESSAGE FROM THE PROGRAM MANAGER

The Human Research Program (HRP) continues to make excellent progress toward understanding and mitigating the health and performance risks that challenge NASA's ability to fly exploration missions beyond low Earth orbit. Our access to space this year was unprecedented; our access to medical data improved substantially; our cooperation with international partners expanded; and, for the first time, NASA engineers asked for our requirements before beginning to design a new space vehicle. By any measure, FY2014 was a banner year with numerous accomplishments, and I am honored to share some of our significant highlights.

The life extension of the International Space Station (ISS) to 2024 announced earlier this year was in part due to the HRP Path to Risk Reduction (PRR). The PRR clearly demonstrated our planned flight research could not be completed with the number of crew slated to fly before its previous decommission date of 2020. While this eased our concerns, there are still likely too few flight subjects to answer all key research questions. To address this limitation, we began working closely with the Human System Risk Board to ensure the likelihood and consequences of each of the risks in our PRR were accurately assessed.

William H. Paloski, Ph.D.
HRP Program Manager

Alternative approaches are being sought to reduce our need for flight subjects, among which is the increased sharing of flight resources with our international partners. Additionally, we are increasing our use of analog environments, both domestic and international, to fine tune solutions prior to flight as well as developing standard outcome measures to be collected on each flight crew research subject.

One success in the analog approach this fiscal year was the completion of four seven-day campaigns in the newly refurbished Human Exploration Research Analog (HERA). This analog is expected to substantially reduce the number of astronaut test subjects required to achieve the Behavioral Health and Performance (BHP) Element risk reduction goals, which are among the most participant-intensive in our PRR.

The ISS-commissioned Multilateral Human Research Panel for Exploration (MHRPE), led by our own Dr. John Charles, had a successful year developing the hardware, data, and subject sharing plans to facilitate the first one-year ISS mission. A group of multinational experiments were selected for this pilot mission—launching in early 2015—which will refine our understanding of extended mission durations on crew health and performance. Preflight data collection and crew training is underway for the one-year crewmembers, Scott Kelly from the U.S. and Mikael Kornienko from Russia. Among the studies planned for this ambitious mission is one investigating the hypothesis that cranial fluid shifts are the primary initiating factor for the visual impairment observed in many recent crewmembers. To carry out this complex study, U.S. hardware will be transported for the first time into the Russian segment to observe the physiological effects of crewmembers exposed to lower body negative pressure in the Russian *Chibis* device.

The "Twins" study, which is part of the one-year mission, will take advantage of the rare opportunity to examine space-related nature versus nurture questions

MESSAGE FROM THE PROGRAM MANAGER

using identical twin brothers. During Scott's one-year mission, his identical twin brother, retired astronaut Mark Kelly, will serve as the ground control subject. Through an open HRP solicitation, we selected ten investigations from a pool of forty outstanding proposals to examine the effects of spaceflight on fundamental biological processes in these two siblings.

With expert leadership from Dr. Craig Kundrot of HRP and Dr. Graham Scott of the National Space Biomedical Research Institute (NSBRI), the Twins investigations coalesced quickly into a single team investigation, which was manifested in record time by our amazing ISSMP Element team. The scope of these investigations ranges across all of the contemporary "omics" sub-disciplines, which includes genomics, epigenomics, proteomics, and also extends to systems physiology and behavioral performance. With these studies, HRP expects to introduce new investigators and systems biology tools into the Program, thereby initiating innovative approaches and solutions to personalized medicine and countermeasures for exploration-class missions.

The Twins investigations have prompted challenging discussions within NASA regarding the privacy and ethics issues associated with collecting and sharing omics data from astronaut subjects. An interim policy was approved for this specific set of investigations, and debate continues toward a permanent agency policy. This work has also developed closer connections and possible collaborations with the GeneLab Project, currently being defined at NASA Headquarters, as well as with the Space Biology and the Center for the Advancement of Science in Space (CASIS) programs.

The Human Research Program is on a success-oriented trajectory. We have recognition and regard at the highest levels of the Agency, continue to attract outstanding investigators to work on our scientific objectives, and are developing strong, collaborative international relationships to create successful collaborations which advance our mutual goals. I remain both optimistic and committed to finding solutions that enable safe, reliable, and productive human space exploration.

William H. Paloski, Ph.D.
Program Manager

In March 2015, American Astronaut Scott Kelly (left) and Russian Cosmonaut Mikhail Kornienko (right) will begin collaborative investigations on the International Space Station (ISS). They will reside on the ISS for a year, which is twice as long as typical U.S. missions.

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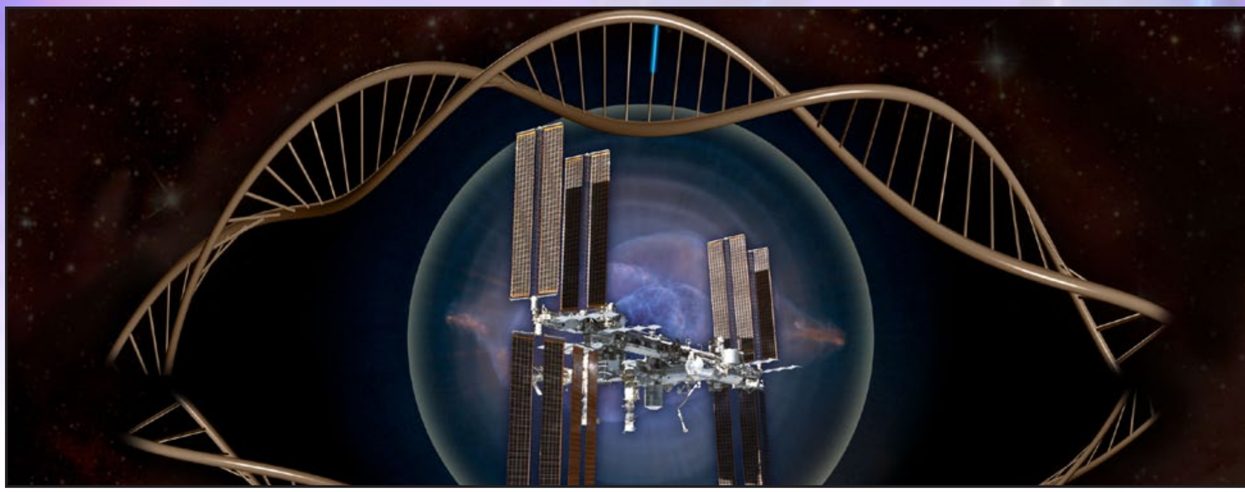


Background

Crew health and performance are critical to successful human exploration beyond low Earth orbit. Hazards include physiologic effects from radiation, hypogravity, and planetary environments, as well as unique challenges associated with the distance from Earth. The scientists and engineers of the Human Research Program (HRP) investigate and reduce the greatest risks to human health and performance, and provide essential countermeasures and technologies for human space exploration.

HRP delivers products and strategies to protect the health and safety of spaceflight crews and increase their productivity while living and working in space. Research is performed onboard the International Space Station (ISS), on the ground in analog environments that have features similar to those of spaceflight, and in laboratory environments. Data from these experiments further the understanding of how the space environment affects the human system. These research results contribute to scientific knowledge and technology developments that address the human health and performance risks from exposure to the hazards of exploration missions.

As shown in this report, HRP continues to make significant progress toward developing medical care and countermeasure systems for space exploration missions which will ultimately reduce risks to crew health and performance.

Goal and Objectives

The goal of the Human Research Program is to provide human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration. The specific objectives of the HRP are:

1) Develop capabilities, necessary countermeasures, and technologies in support of human space exploration, focusing on mitigating the highest risks to crew health and performance. Enable the definition and improvement of human spaceflight medical, environmental and human factors standards.

2) Develop technologies that serve to reduce medical and environmental risks, to reduce human systems resource requirements (mass, volume, power, data, etc.) and to ensure effective human-system integration across exploration mission systems.

3) Ensure maintenance of Agency core competencies necessary to enable risk reduction in the following areas: space medicine, physiological and behavioral effects of long duration spaceflight on the human body, space environmental effects, including radiation, on human health and performance and space human factors.

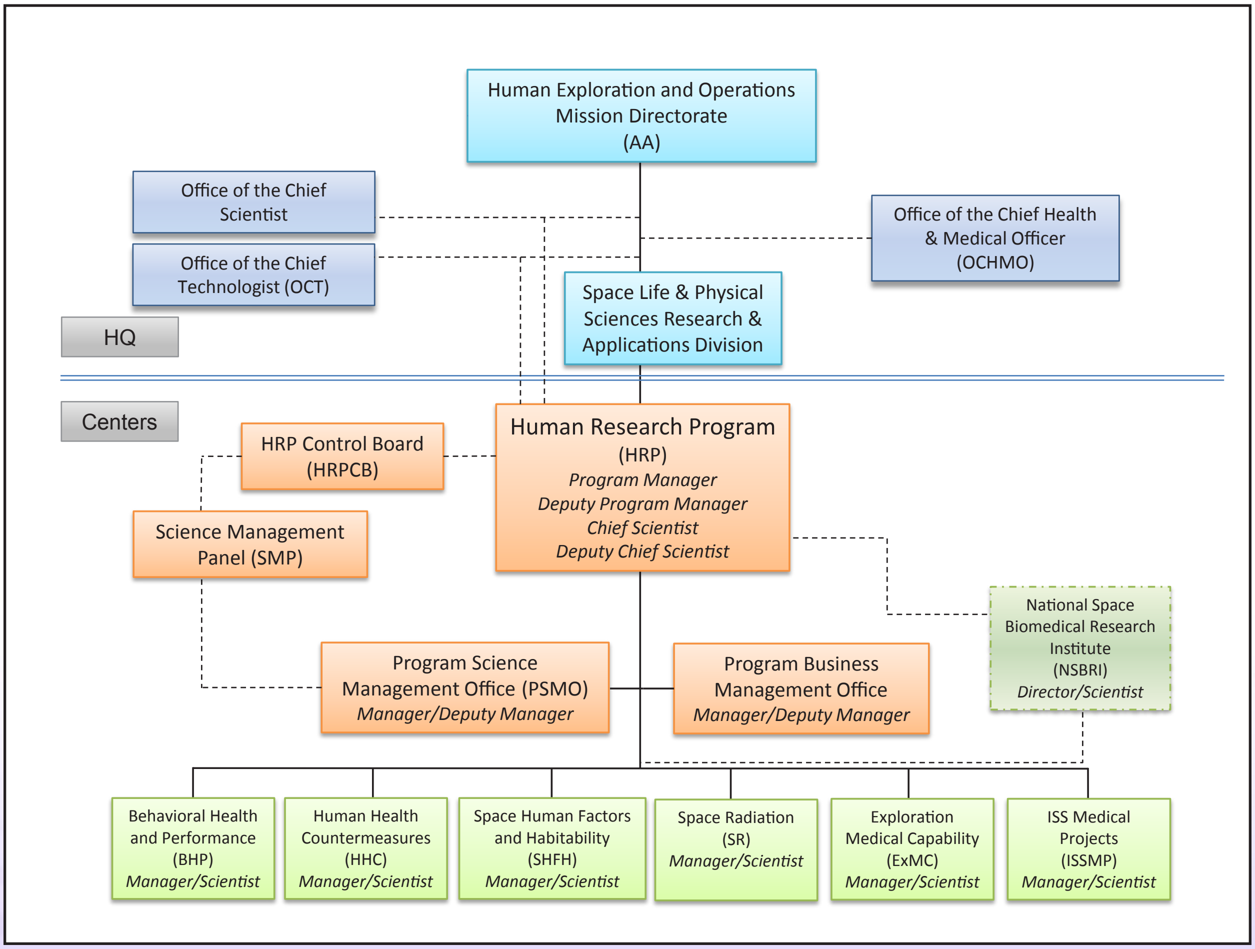
Program Organization

The HRP's organization is designed to support the goals of the Human Exploration and Operations Mission Directorate (HEOMD) and NASA's Office of the Chief Health and Medical Officer (OCHMO). To that end, HRP conducts research and develops technology that enables the OCHMO to establish and maintain NASA-wide human health and performance standards. Furthermore, HRP provides HEOMD with methods of meeting those standards in the design, development, and operation of technological systems for exploration missions.

Organizationally, HRP resides within the HEOMD; however, the management of HRP is located at the Johnson Space Center and work is performed across multiple participating NASA centers. The HRP Program Manager and Deputy Manager lead all aspects of the program and the HRP Chief Scientist and Deputy Chief Scientist lead the science management and coordination.

As shown in the chart below, two offices support program, science and business management and provide integration across the Program. The Program Science Management Office (PSMO), and the Program Business Management Office provide coordination of HRP activities across all Program components.

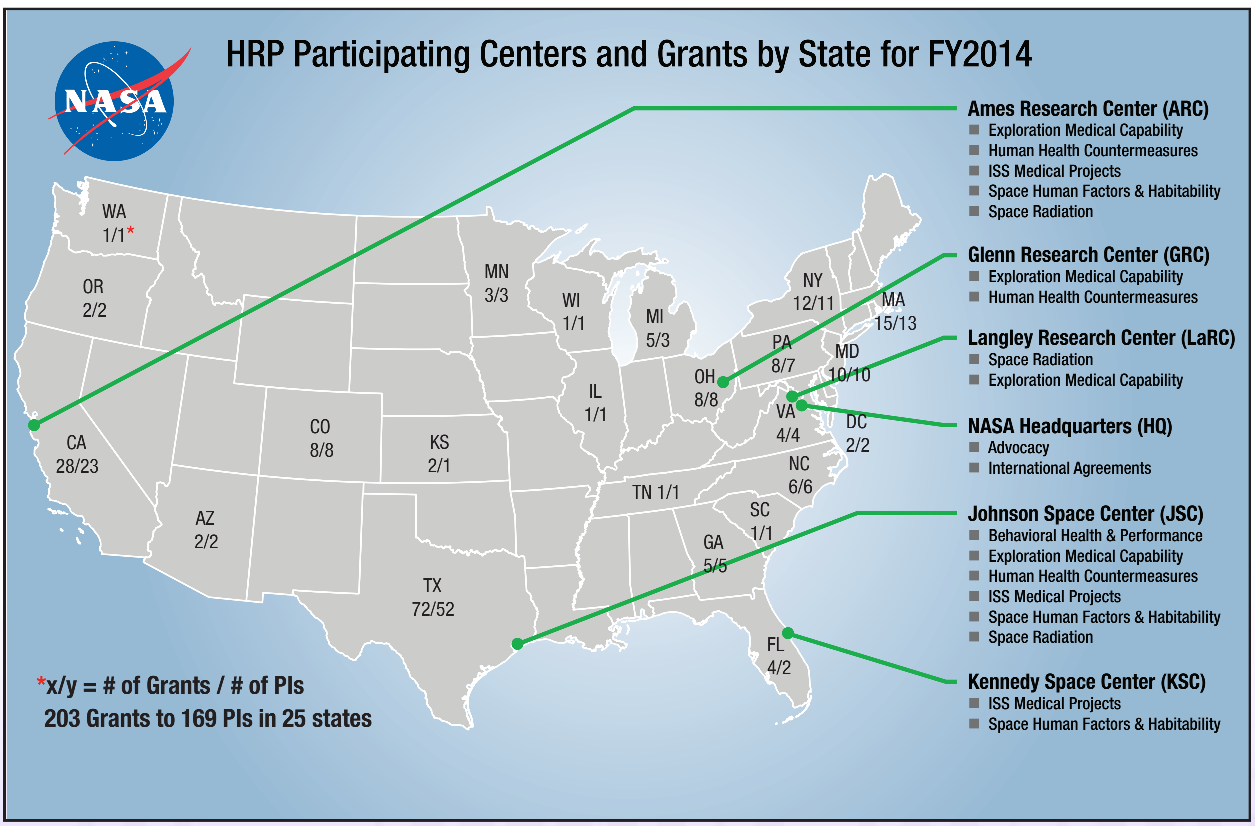
The PSMO maintains scientific integrity of the HRP's research, reviews and integrates science tasks, reviews



the prioritization and implementation of flight and ground analog tasks, communicates research needs to other NASA programs and cultivates strategic research partnerships with other domestic and international agencies. The Program Business Management Office maintains all business functions for the Program, providing budget planning, integration and coordination with the HEOMD and across all Program components.

There are six Elements that comprise the Program and are focused to accomplish specific goals for investigating and mitigating the highest risks to astronaut health and performance. Of the six, five are research Elements and one, ISSMP, is a service element which provides the other Elements access to the ISS and ground-based analogs. The research Elements include: Space Radiation, Human Health Countermeasures, Exploration Medical Capability, Space Human Factors and Habitability, and Behavioral Health and Performance. These Elements provide the HRP's knowledge and capabilities to conduct research to address human health and performance risks of spaceflight, and they advance the readiness levels of technology and countermeasures to the point where they can be transferred to the customer programs and organizations. As shown below, the HRP is a multi-center program, with research being performed across the nation.

Each research Element consists of related portfolios, projects and research tasks focused toward developing products that reduce the highest risks in that area. To learn more about the HRP Elements, please visit: http://www.nasa.gov/exploration/humanresearch/elements.



OVERVIEW

Partnerships and Collaborations

The HRP has a long history of collaborative work with universities, hospitals, and federal and international agencies for the purpose of sharing research facilities and multi-user hardware, and cooperation on research tasks of mutual interest.

The National Space Biomedical Research Institute (NSBRI), an academic institute funded by HRP, investigates the physical and psychological challenges of long-duration human spaceflight. Founded in 1997 through a NASA competition, NSBRI is a nonprofit research consortium that connects the research, technical, and clinical expertise of the biomedical community with the scientific, engineering, and operational expertise of NASA. NSBRI is located within the Baylor College of Medicine's Center for Space Medicine. For more information, visit www.nsbri.org.
The HRP also maintains collaborative relationships with international partners through various working groups. These relationships enhance the research capabilities of all partners and provide synergism of research efforts.

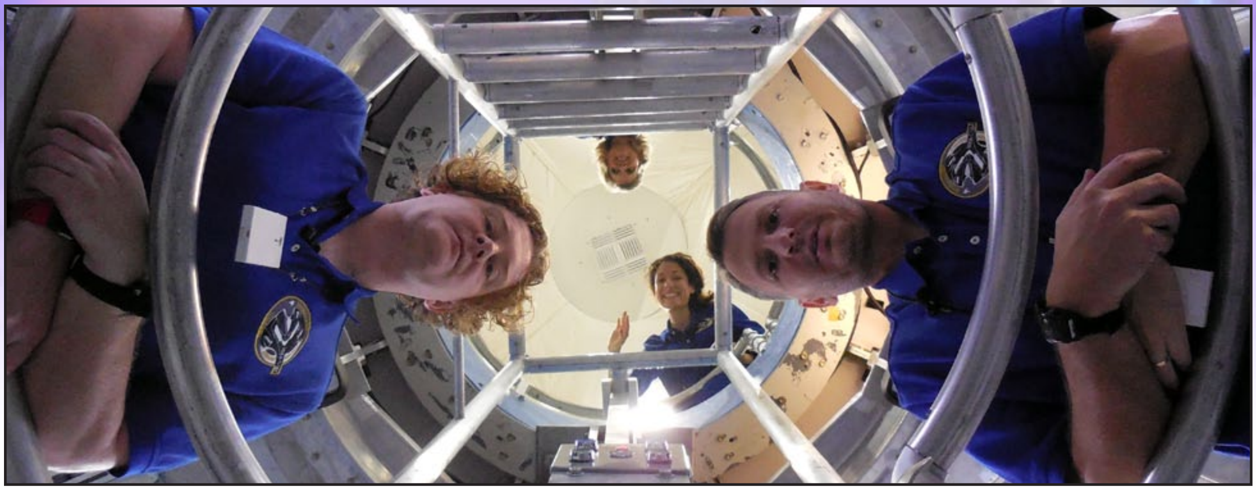
In 2014, HRP used bed rest facilities at the University of Texas Medical Branch in Galveston, Texas, to study changes in physiologic function associated with weightlessness. Many of these changes occur in people subjected to bed rest with the head tilted downward at a 6-degree angle. Starting in 2015, HRP will close their facilities in Galveston to begin a new era in international collaboration. Future bed rest studies are planned to be multi-lateral studies run in a new facility constructed by the Deutsches Zentrum für Luft- und Raumfahrt (DLR) in Koln, Germany.

The NASA Space Radiation Laboratory (NSRL) at the Department of Energy's Brookhaven National Laboratory in Upton, New York, conducts research using accelerator-based simulations of space radiation.

Partnerships and Collaborations with Universities, Industries, and Government Agencies

Examples of HRP Partnerships and Collaborations	Benefits to Exploration
National Space Biomedical Research Institute (NSBRI)	Investigates the challenges of long-duration human spaceflight and bridges the expertise of the biomedical community with the scientific, engineering, and operational expertise of NASA
US-Russian Joint Working Group (JWG)	Broaden ISS research and enhance opportunities for collaboration
Multilateral Medical Operations Panel (MMOP)	Multilateral hardware and data collaborations between ISS operations and HRP research.
Multilateral Human Research Panel for Exploration (MHRPE)	Permanent steering group for duration of ISS program. Integrates data and strategies from operations and research. Leverages existing processes among implementation groups.
International Human Space Flight Analog Research Coordination Group (HANA)	Coordinates isolation and confinement research in analog environments across the multiple international partnering agencies.
International Space Life Sciences Working Group (Canada, Japan, Germany, Ukraine, France, and the European Space Agency)	Encourages a unified effort among space life sciences communities around the world by coordinating the use of spaceflight and ground research facilities and identifying mutual interests and compatibilities

Examples of HRP Partnerships and Collaborations	Benefits to Exploration
National Institutes of Health, Department of Energy, Centers for Disease Control and Prevention, Department of Agriculture, Department of Defense	State-of-the-art research facilities, research activities, and technology development of mutual interest
Cleveland Clinic Center for Space Medicine	Provides collaboration and consultation regarding HRP research
National Oceanic & Atmospheric Administration (NOAA) at the Aquarius Undersea Habitat	NASA Extreme Environment Mission Operations (NEEMO) uses this undersea habitat as an analog
University of Texas Medical Branch, Galveston, TX	Provides bed rest facilities to study changes in physiologic function associated with weightlessness
Department of Energy - Brookhaven National Laboratory	State-of-the-art facility conducts research using accelerator-based simulation of space radiation
Summa Health Systems	Provides collaborative research for advanced health care delivery to astronauts
European Space Agency (ESA)	Collaboration on the utilization of the Pulmonary Function System, MARES, and exercise research
Japan Aerospace Exploration Agency (JAXA)	Research on bone-related risks, auscultation capabilities, and utilization of environmental sampling
Institute for Biomedical Problems (IBMP)	Coordination of the 1-year mission and functional performance Field Test Experiment and VIIP research
SHAPE America	Collaborating and co-promoting Train Like an Astronaut Project
University at Buffalo, Department of Epidemiology and Environmental Health	Collaborating on topics in pediatric obesity and program evaluation for MX and TLA
Texas Instruments	Content and curriculum development for the HREC Math and Science @ Work, Exploring Space Through Math and Science, and 21st Century Explorer projects
Destination Station, and ISS Program outreach and outreach feature press releases	Public dissemination of HREC information on the Human Challenges of Space Exploration
The Jamestown Resource Center	Collaboration on HREC content to be used for those with unique needs and their participation in the Train Like an Astronaut (TLA) activities
Let's Move! Initiative	TLA materials co-branded with this White House Initiative
International space agency education support with world-wide community partners and schools	Collaborative partnerships fostering the world-wide dissemination of HREC *Mission X: Train Like an Astronaut* physical and educational activities encouraging better nutrition and healthier lifestyles for children



HERO Research Solicitations and Selections

In FY2013, HRP transitioned to a new NASA Research Announcement (NRA) format to be more responsive and flexible. Historically, one research announcement was issued in July, resulting in selection of proposals in April of the following year. The new Human Exploration Research Opportunities (HERO) NRA is a solicitation that remains open all year with research opportunities, or appendices, being issued as needed.

HRP issued eight appendices in FY2013 including NASA Flagship, NASA Omnibus, NSBRI, Differential Effects on Homozygous Twin Astronauts Associated with Differences in Exposure to Spaceflight Factors, Ground-Based Studies in Space Radiobiology, International Life Sciences Research, NASA Specialized Centers of Research for Ground-Based Studies in Cancer Risks and Cognitive and Behavioral Central Nervous System Risks from Space Radiation, and Behavioral Health and Performance. In summary, HRP received 327 Step-1 proposals and 209 invited Step-2 proposals and issued 46 new awards.

For the 2014 HERO NRA, HRP received 180 Step-1 proposals submitted in response to the Flagship, Omnibus, and NSBRI appendices and 122 invited Step-2 proposals. Final NRA selections will be announced in April 2015.

The NRA "NASA Specialized Centers of Research (NSCORs) for Ground-Based Studies in Cancer Risks and Cognitive and Behavioral Central Nervous System Risks from Space Radiation" was released in May 2014. Proposals were solicited to use facilities at the NSRL. A peer review was conducted in November 2014 to evaluate 12 Step-2 proposals, and the final selections were announced in December.

In cooperation with NASA's international partners, the International Life Sciences Research Announcement was released in February 2014. Topics included intracranial pressure, team task switching in astronaut crews, bioregenerative food systems, and habitable volume and space utilization assessment tool validation. Peer review of the 20 Step-2 proposals occurred in September, and final selections will be announced in January.

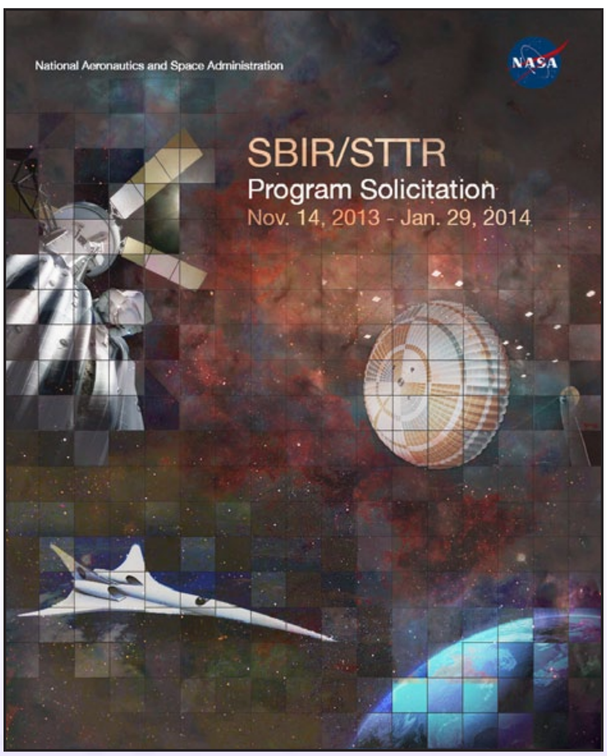
NRA Research Solicitations and Selections

Eleven proposals were received in response to the NRA titled "Behavioral Health and Performance," issued in May 2014. Topics included Neurobehavioral Conditions List for Characterizing Behavioral Health Risk for Exploration Missions, Standardized Behavioral Measures, and Evaluation of the Neurobehavioral Effects of a Dynamic Lighting System on the ISS. Peer review of the proposals occurred in August, and three final selections were announced in September.

The NRA "Ground-Based Studies in Space Radiobiology" was released in February 2014. It solicited proposals for ground-based research in the areas of Cancer, Central Nervous System, and Degenerative Risks from Space Radiation. Proposals were solicited to use charged particles to simulate space radiation at the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory. A peer review was conducted in August 2014 to evaluate 54 Step-2 proposals, and awards were announced in October 2014.

SBIR Research Solicitations and Selections

The NASA Small Business Innovation Research (SBIR) Program Management Office released the 2014 SBIR Phase 1 Solicitation in November 2013. The four HRP topics included in the solicitation were Exploration Medical Capability, Behavioral Health and Performance, Advanced Food Systems Technology, and In-Flight Biological Sample Analysis. Five HRP 2014 SBIR Phase 1 awards were announced in April 2014. In addition, three HRP 2012 SBIR Phase 2 awards were announced in March 2014. Information on awards may be found at http://sbir.gsfc.nasa.gov



The SBIR program is a competitive 3-phase award system which provides small businesses with opportunities to propose innovations to meet specific research and development needs.

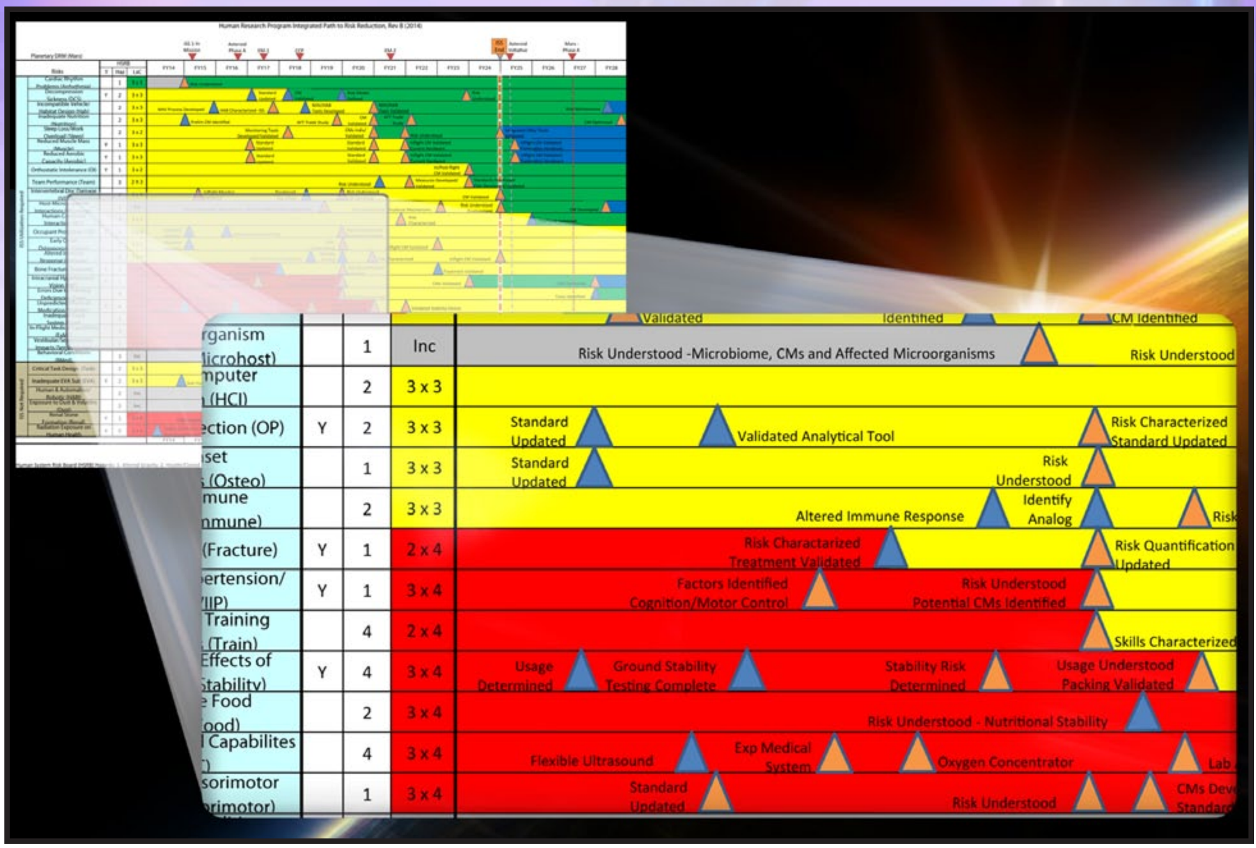
Path to Risk Reduction Communicates HRP Plan to Reduce Risks to Reasonable Level

In March 2013, in support of the Program's evidence and risk-based management approach, HRP developed a new method to communicate the Integrated Path to Risk Reduction (iPRR) for risks in the HRP portfolio. During 2014, HRP completed documenting the detailed logic and schedules required to drive each risk's PRR.

The iPRR is designed to communicate plans and progress towards reducing the risks to humans during exploration missions. The iPRR is a summary of the initial risk posture, as determined by the Human System Risk Board (HSRB) and HRP's Integrated Research Plan (IRP). The IRP identifies key capabilities or knowledge required to reduce the risk; the research required to fill the gaps; and the platform required for the research. This research is then transposed on a notional timeline with the appropriate logical connections to project when in the future the knowledge and capabilities are available for a reasonable risk posture in support of a particular mission. The IRP can be viewed at http://humanresearchroadmap.nasa.gov.

Significant progress was made by the HSRB in 2014 to document the hazards associated with exploration missions, the risks due to those hazards and the risk posture for each risk during various types of exploration missions. The risk posture is based on current knowledge, requirements and technology, and the HSRB determines whether this is sufficient to control the risk to an acceptable level for future missions. A subset of the risks identified by the HSRB are included in the HRP research portfolio.

Through the iPRR, HRP is able to communicate the importance of the ISS in reducing risks for exploration. This effort played an important role in the



HRP's new Integrated Path to Risk Reduction (iPRR) document combines risk data with timelines and milestones to inform management on the status of risk mitigation for future exploration-class missions—in this case Mars.

decision to extend the ISS to 2024 and ensure HRP remains a high priority in ISS utilization.

Potential for Additional 1-year Missions Increase Future Research Opportunities

Astronaut crews typically spend about six months on the ISS. NASA's first one-year mission to the ISS is scheduled to begin in March 2015. In 2013, HRP was asked by JSC management and the ISS Program to determine if there would be value in having additional ISS missions of one year's duration: would this be beneficial to HRP's goal of mitigating the major risks to human health and performance in exploration missions? Given that an eventual human mission to Mars will be longer than six months, and the journey in one direction might be longer than six months, it seemed prudent to consider the value of these longer missions in providing a better understanding of the health and performance risks and their mitigation.

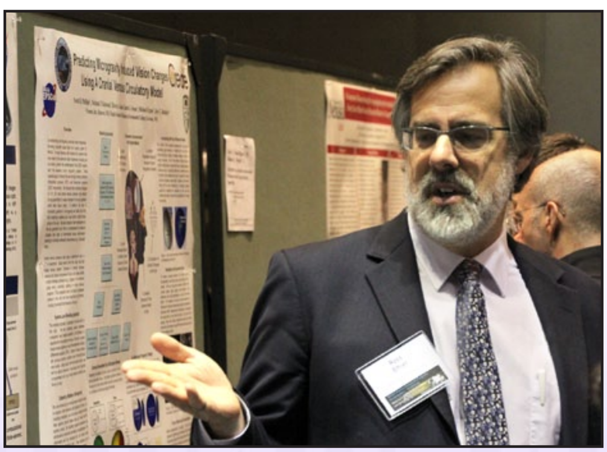
After a thorough review of the HRP research portfolio, three key areas were identified: medical conditions with a temporal trend of increasing severity with time in space; behavior and performance issues related to extended periods of isolation and confinement; and physiological deconditioning—such as deficits in bone, muscle, cardiovascular function, and exercise performance. For each of these, plans are being developed to monitor the effects of year-long missions for comparison with research findings from six-month missions.

Briefings on the HRP findings were given to key stakeholders, including the ISS Program Manager and the Associate Administrator of the Human Exploration and Operations Mission Directorate. In addition, the HRP International Science Office is working with its international partners for their concurrence. To date, the ISS Program Office is planning for two additional one-year missions—hopeful that more will follow. In this effort HRP continues to be a primary user of the ISS, performing the research needed to enable future exploration missions to be flown far from Earth.

Record Attendance for 2014 Investigators' Workshop

The 2014 HRP Investigators' Workshop was held February 11-13 in Galveston, Texas. The theme of the workshop was "Challenges and Opportunities: Maximizing Human Space Flight Research." This year's workshop, which combined the Behavioral Health and Performance Working Group and the Space Radiation Element Investigators' Workshop, was the largest ever, with 797 registrants from 10 countries and 335 abstracts submitted.

The meeting is the primary venue for HRP and NSBRI researchers to share their findings. It included three plenary sessions, 36 discipline-specific sessions and 2 poster sessions. The NASA Chief Scientist welcomed attendees with a video message and the NASA Deputy Chief Scientist provided opening remarks. During the opening plenary, a talk was presented on the Vision of Integrated Omics for Human Space Exploration.



The Investigators' Workshop features poster sessions which allow researchers to present and explain their research findings.

Sessions also included a statistics presentation, a panel on the Inspiration Mars Project, and a student poster competition and Pioneer Awards sponsored by NSBRI. In the closing plenary the HRP International Science Office Chief presented International Data Sharing, and the ISS Program Scientist presented a strategic approach to ISS utilization. The meeting program and abstracts can be viewed at: http://www.hou.usra.edu/meetings/hrp2014.

Utilization and Development of NSBRI's Consolidated Research Facility Continues

During 2014, NSBRI's Consolidated Research Facility (CRF) hosted multiple scientific meetings, advanced technology demonstrations (ATDs) and countermeasure assessments. Recently, 5 cross-disciplinary scientific workshops and 16 ATDs took place at the CRF. These events were organized by NSBRI and NASA HRP scientists and managers.

These favorably reviewed meetings and activities and the development of four laboratories are transforming the Institute. NASA personnel have enthusiastically attended these events and have embraced the opportunity to discuss operational and research requirements with the broader external scientific community. The new laboratories include the Astro-omics, Biomedical Innovation, Extreme Medicine, and Advanced Technology Demonstration Laboratories.

NSBRI's Consolidated Research Facility is located in the Bioscience Research Collaborative on the Rice University campus.

Meetings and demonstrations held at the CRF tangibly engage and harness the academic and business communities by bringing together subject matter experts who, in many cases, would not normally advise or interact with NASA personnel. In addition, these meetings are highly valuable to HRP by helping consolidate and communicate the current state of knowledge, update evidence books, mitigate risks, close gaps, and recommend new promising avenues of research.

The Twins Study: Unique 1-Year Mission to Feature Molecular '-Omics' Research

HRP solicited and selected ten short-term, first-of-their-kind investigations leveraging a unique set of subjects—identical twins. This opportunity emerged from NASA's decision to fly veteran NASA astronaut Scott Kelly aboard the ISS for one year beginning in March 2015, while his identical twin brother, retired NASA astronaut Mark Kelly, remains on Earth. The investigations will examine the differences in genetic, proteomic, metabolomic, and related functions associated with differential exposure of identical twin male astronauts to spaceflight conditions.

HRP solicited proposals that focused on the use of integrated human "-omic" analyses, to better understand the biomolecular responses to the physical, physiological, and environmental stressors associated with spaceflight. Out of 40 proposals, ten were selected and all ten investigators will function together as one team to examine the effects of spaceflight across a wide set of analyses. This integrated project includes the following analyses: genome, epigenome, transcriptome, proteome, metabolome, microbiome, physiology, and neurobehavior. In addition to bringing 21st-century omics research to NASA, this study also serves as a pathfinder for addressing technical and ethical issues associated with such research.

Scott Kelly, a veteran of two Space Shuttle flights as well as a six-month ISS mission, will have a cumulative duration of 540 days in low Earth orbit at the conclusion of the one-year flight, whereas Mark Kelly, a veteran of four Space Shuttle flights, has a cumulative duration of 54 days in low Earth orbit.

Scott Kelly (left) will participate in the first '1-Year Mission' while his identical twin brother Mark Kelly (right) remains on Earth. Both are subjects in the 'Twins Study' which will include '-omics' analyses to examine molecular changes.

Experts in Complexity Theory Advise HRP on Addressing Cross-Disciplinary Interactions

Almost every system in the body is affected in some way when people go into space for extended periods. Spaceflight effects encompass not only physiological changes such as bone loss and altered immune function, but also behavior and performance issues such as circadian rhythms, sleep, and alertness. Although many of these changes are well understood, they are studied mainly in a segregated fashion, one system at a time, ignoring the strong connections between them. A few HRP studies are now examining cross-disciplinary interactions, but there has not previously been a systematic approach to identifying these interactions and investigating them.

HRP is in the early stages of addressing this problem. In the fall of 2014, several HRP Standing Review Panels met in an integrated session, specifically to explore areas of collaboration that could be included in HRP research. Additionally, members of the Santa Fe Institute (SFI) met with representatives from HRP in September 2014. SFI is a pioneer in the study of complexity theory: emergent properties of highly

PROGRAM-WIDE

interconnected subsystems, their resilience, and their ability to self-organize.

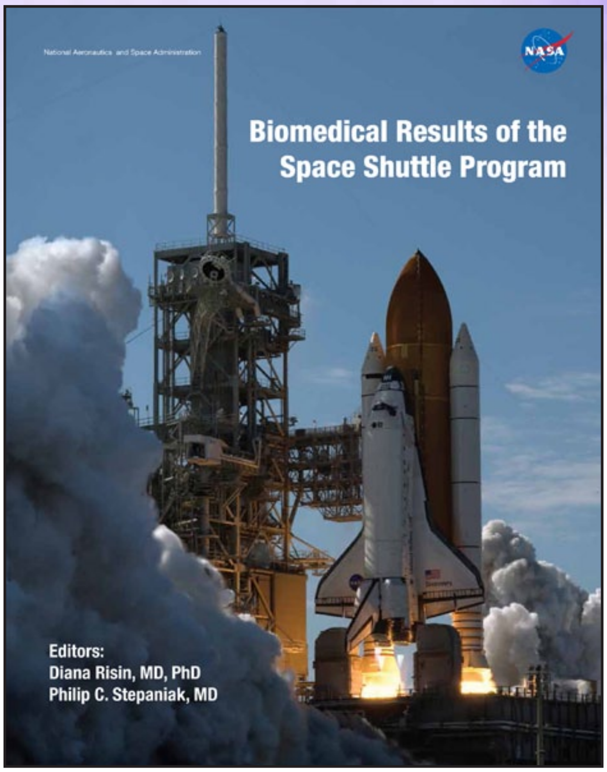
SFI members were briefed on the challenges of human spaceflight and discussed areas of collaboration in applying complexity theory and integrative approaches to these problems. An integrated approach to human space adaptation would take into account the interconnections between body systems and help design more efficient countermeasures that address multiple factors simultaneously and with increased efficiency.

Biomedical Results of the Space Shuttle Program Book Published

The Space Shuttle Program (SSP), completed by the flight of STS-135, holds a special place in the history of human space exploration. Many important questions about the ability of humans to adapt and function in space were answered during the 30 years of the SSP, and many lessons have been learned. The multidisciplinary studies conducted during this program allowed NASA to define the normal responses to short-duration spaceflight and potential pathologic changes in the major physiological systems. These findings significantly contributed to the development of in-flight medical care capabilities and multiple countermeasures. A comprehensive system of preflight, in-flight, and postflight monitoring of the astronauts was built.

The book, *Biomedical Results of the Space Shuttle Program*, published in November 2013, provides a comprehensive review of the biomedical results of the SSP. The book summarizes life sciences experiences, accomplishments, and lessons learned from medical operations activities and biomedical research during the Space Shuttle missions. It defines the normal responses of the major physiological systems to short-duration spaceflights and provides an invaluable source of information for planning and ensuring successful operational activities and management of potential medical problems that might arise during future long-term space missions.

A hardcover version of the book can be purchased at http://bookstore.gpo.gov/products/sku/033-000-01363-9.



A comprehensive review of thirty years of short-duration shuttle flights is published in the book, Biomedical Results of the Space Shuttle Program.

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INTERNATIONAL SPACE STATION MEDICAL PROJECTS ELEMENT

ISSMP

Overview

The International Space Station Medical Projects (ISSMP) Element provides planning, integration, and implementation services for HRP research studies. ISSMP supports both spaceflight and flight analog research. Through the integration of these two efforts, ISSMP offers an innovative way to guide research decisions to meet the unique challenges of understanding the human risks of space exploration.

The objectives of ISSMP are to maximize the utilization of the ISS and flight analog environments and to develop and verify strategies to ensure optimal crew performance for exploration missions. The ISSMP also enables the development and validation of physical, pharmacologic, and nutritional countermeasures sponsored by HRP research Elements that influence mission success or crew health.

ISSMP supports HRP flight and flight analog investigations by coordinating research activities before, during, and after missions. Services provided by ISSMP include training of crewmembers and ground controllers; monitoring real-time experiment and hardware operations; and facilitating the transfer of data to research investigators.

ISSMP provides and sustains the Human Research Facility on the ISS which is available for investigators who wish to conduct human physiological research. ISSMP also facilitates the development and certification of new flight hardware, coordinates the manifest of consumables for in-flight data collection, and provides complete integration support for multiple flight vehicles including the Russian Soyuz and Progress, and European, Japanese, and commercial launch vehicles. During flight research operations, ISSMP maintains the JSC Telescience Support Center (TSC). The TSC provides a focal point for real-time ISSMP operations and for remote investigators to monitor their experiments and acquire telemetry data.

Additionally, ISSMP coordinates with the ISS International Partners to develop integrated, mission-specific science complements of experiments for flight investigations and to negotiate schedules and usage agreements, and crewmember participation.

The Flight Analogs Project (FAP) team within ISSMP provides and manages the Flight Analog Research Unit (FARU) and the Human Exploration Research Analog (HERA) facilities in which HRP-sponsored research is conducted. The FARU is a dedicated bed rest facility specializing in head-down bed rest and located at the University of Texas Medical Branch at Galveston. This facility functions under a set of uniform operating conditions to ensure consistency across all studies, and maximizes resources by combining individual investigations into integrated

During FY2014, investigators used the HERA facility for four 7-day isolation study missions.

studies. The HERA facility provides a platform for conducting HRP isolation and confinement studies under controlled mission conditions.

The use of ground analogs, such as bed rest and HERA, are essential for HRP research efforts because access to resources needed to conduct studies in space are limited. The overall expense of ground studies is significantly less than flight and allows for a greater number of subjects. Flight analog testing will become increasingly critical to NASA to validate countermeasures because the opportunities to use flight platforms such as the ISS are few and the number of crewmembers per mission is limited.

The FAP also assists researchers by characterizing current and potential spaceflight analogs, evaluating their relevance and similarity to spaceflight conditions, and matching the characteristics of analogs to research requirements. Examples of other analog environments are extreme environments such as undersea habitats, remote desert test sites and Antarctic outposts. To learn more, visit: http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-issmp.html

FY2014 Overview and Highlights

In FY2014, the ISSMP coordinated the flight research supporting ISS Increments 37-41. Accomplishments include the completion of 2 flight studies and 16 continuing studies. Also in FY2014, one new investigation began flight operations, seven new investigations initiated development of flight requirements to support future missions, and three investigations are undergoing feasibility assessments awaiting a future select-for-flight decision. ISSMP supported 374 in-flight sessions from the TSC, resulting in the use of 656.83 hours of crew time on orbit. ISSMP also conducted 135 crew training sessions, and coordinated nearly 500 pre- and post-flight baseline data collection (BDC) sessions. Additionally, ISSMP supported our International Partners by participating in nine technical readiness reviews for their BDC sessions. The following table lists all active flight experiments, the number of subjects required, and progress.

Current International Space Station Medical Projects Flight Investigations

Investigation Title	Ops Title	Investigator and Institution	Subjects: Required	Subjects: Participation Through Increment 41
Investigations Continuing Flight Operations in Fiscal Year 2014				
NASA Biochemical Profile Project	Biochem Profile	Scott Smith, PhD *NASA/JSC*	All US Astronauts	6
Bisphosphonates as a Countermeasure to Space Flight Induced Bone Loss	Bisphos-phonates (CONTROL)	Adrian LeBlanc, PhD *USRA* Toshio Matsumoto, MD, PhD *University of Tokushima*	10	7

Investigation Title	Ops Title	Investigator and Institution	Subjects: Required	Subjects: Participation Through Increment 41
Quantification of In-flight Physical Changes – Anthropometry and Neutral Body Posture	Body Measures	Sudhakar Rajulu, PhD *NASA/JSC*	12	5
Defining the Relationship Between Biomarkers of Oxidative and Inflammatory Stress and the Risk for Atherosclerosis in Astronauts during and after Long-Duration Spaceflight	Cardio Ox	Steven H. Platts, PhD *NASA/JSC*	12	4
Physiological Factors Contributing to Changes in Post-Flight Functional Performance	FTT	Jacob Bloomberg, PhD *NASA/JSC*	13 Shuttle 13 ISS	7 Shuttle 13 ISS
Occupational Risk Surveillance for Bone: Pilot Study-Effects of In-Flight Countermeasures on Sub-Regions of the Hip Bones	Hip QCT	Jean D. Sibonga, PhD *NASA/JSC*	10	9
Risk of Intervertebral Disc Damage After Prolonged Spaceflight	IVD	Alan R. Hargens, PhD *Univ. of California - San Diego*	12	4
Behavioral Issues Associated with Long Duration Space Expeditions: Review and Analysis of Astronaut Journals	Journals (6 crew)	Jack Stuster, PhD *Anacapa Sciences, Inc.*	10	9
Assessment of Operator Proficiency following Long-Duration Spaceflight	Manual Control	Steven T. Moore, PhD *Mount Sinai School of Medicine*	8	7
Study of the Impact of Long-Term Space Travel on the Astronaut's Microbiome	Microbiome	Hernan Lorenzi, PhD *J. Craig Venter Institute, Inc.*	9	5
Prospective Observational Study of Ocular Health in ISS Crews	Ocular Health	Christian Otto, MD *Universities Space Research Association (USRA)*	12	6
Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism During Spaceflight and Recovery	Pro K	Scott Smith, PhD *NASA/JSC*	16	17
Psychomotor Vigilance Self Test on ISS	Reaction Self Test	David Dinges, PhD *University of Pennsylvania*	24	24
NASA Biological Specimen Repository	Repository	Kathleen McMonigal, MD *NASA/JSC*	All	39
The Effects of Long-Term Exposure to Microgravity on Salivary Markers of Innate Immunity	Salivary Markers	Richard J. Simpson, PhD *University of Houston*	6	4
Integrated Resistance and Aerobic Training Study	Sprint	Lori Ploutz-Snyder, PhD *NASA/JSC*	20 Control 20 Active	6 Active 3 Control

Investigation Title	Ops Title	Investigator and Institution	Subjects Required	Subjects Participation Through Increment 41
Investigations with Initial Flight Operations in Fiscal Year 2014				
Factors Contributing to Food Acceptability and Consumption, Mood and Stress on Long-term Space Missions	Astro Palate	Zata Vickers, PhD *University of Minnesota*	8	0
Individualized Real-Time Neurocognitive Assessment Toolkit for Space Flight Fatigue	Cognition	Mathias Basner, MD, PhD *University of Pennsylvania*	6	0
Recovery of Functional Sensori-motor Performance Following Long Duration Space Flight	Field Test	Millard Reschke, PhD *NASA/JSC* Inessa B. Kozlovskaya, MD *Russian Federation/IBMP*	15	0
Fluid Shifts Before, During and After Prolonged Space Flight and Their Association With Intracranial Pressure and Visual Impairment	Fluid Shifts	Michael Stenger, PhD *Wyle ST&E/NASA JSC* Scott Dulchavsky, MD, PhD *Henry Ford Health System* Alan R. Hargens, PhD *Univ. of California San Diego*	10	0
In-flight Demonstration of Portable Load Monitoring Devices – Phase I: XSENS ForceShoe™	Force Shoes	Andrea M. Hanson, PhD *NASA/JSC*	N/A	N/A
Spaceflight Effects on Neurocognitive Performance: Extent, Longevity and Neural Bases	Neuro-Mapping	Rachel D. Seidler, PhD *University of Michigan*	13	0
Sleep-Wake Actigraphy and Light Exposure on ISS12	Sleep 1YM	Laura Barger, PhD *Brigham and Women's Hospital/ Harvard Medical School*	2	0
Effects of Long-Duration Spaceflight on Training Retention	Training Retention	Immanuel Barshi, PhD *NASA/ARC*	6	0
Investigations Completing In-Flight Operations in Fiscal Year 2014				
Assessing the Impact of Communication Delay on Behavioral Health and Performance: An Examination of Autonomous Operations Utilizing the ISS	Comm Delay Assessment	Lawrence A. Palinkas, PhD *Univ. of Southern California*	3	3
Sonographic Astronaut Vertebral Examination	Spinal Ultrasound	Scott Dulchavsky, MD, PhD *Henry Ford Health System*	6	7

Investigations Initiating Flight Development Activities in Fiscal Year 2014				
Human Cerebral Vascular Autoregulation and Venous Outflow In Response to Microgravity-Induced Cephalad Fluid Redistribution	Cephalad Fluid Re-distribution	Donna Roberts, MD *Medical Univ. of South Carolina*	8	0
Dose Tracker Application for Monitoring Crew Medication Usage, Symptoms and Adverse Effects During Missions	Dose Tracker	Virginia E. Wotring, PhD *Universities Space Research Association (USRA)*	24	0
Effects of Long-duration Microgravity on Fine Motor Skills: 1-year ISS Investigation	Fine Motor	Kritina Holden, PhD *NASA/JSC*	8	0
Habitability Assessment of International Space Station	ISS Habitability	Sherry S. Thaxton, PhD *Lockheed Martin/NASA JSC*	6	0
Medical Consumables Tracking	Medical Consumables Tracking	John T. Zoldak *Zin Technologies/NASA GRC*	N/A	N/A
Assessing Telomere Lengths and Telomerase Activity in Astronauts	Telomeres	Susan M. Bailey, PhD *Colorado State University*	10	0
Differential Effects on Homozygous Twin Astronauts Associated with Differences in Exposure to Spaceflight Factors	Twins Study	Susan M. Bailey, PhD *Colorado State University* Mathias Basner, MD, PhD *University of Pennsylvania* Andrew Feinberg, MD, MPH *Johns Hopkins University* Stuart M. C. Lee, MS *Wyle ST&E/NASA JSC* Christopher Mason, PhD *Cornell University* Emmanuel Mignot, PhD *Stanford University* Brinda K. Rana, PhD *University of California* Scott Smith, PhD *NASA/JSC* Michael Snyder, PhD *Stanford University* Fred Turek, PhD *Northwestern University*	2	0
Investigations Awaiting Select for Flight Decision				
Deep Space Exploration Atmosphere Effects on Hematologic, Immunologic, and Oxidative Stress and Damage Parameters in Astronauts: An ISS Flight Study	Exploration Atmosphere	Brian E. Crucian, PhD *NASA/JSC*	17	0

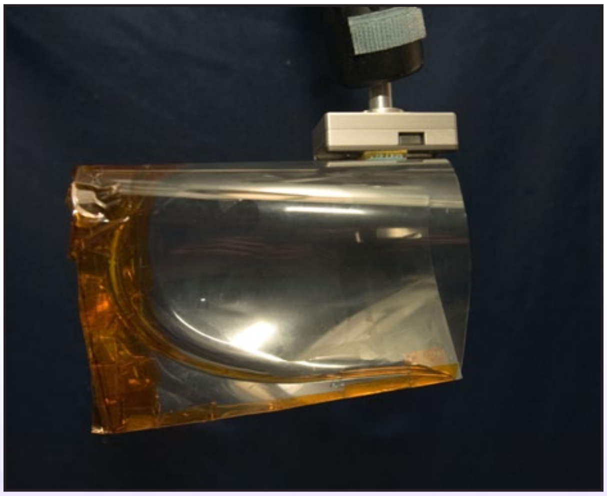
ISSMP

Investigation Title	Ops Title	Investigator and Institution	Subjects	
			Required	Participation Through Increment 41
Integrated Nutrition: Development and Provision of Functional Foods to Mitigate Bone Loss on ISS Missions	Integrated Nutrition	Scott Smith, PhD *NASA/JSC*	24	0
Effects of long duration spaceflight on venous and arterial compliance in astronauts	Vascular Compliance	Michael Stenger, PhD *Wyle ST&E/NASA JSC*	8	0

NASA@Work Challenge Provides a Unique Solution to Capture ISS Urine Samples

Urine samples are commonly used to assess an astronaut's health as well as conduct research in physiological disciplines by measuring key biomarkers. Currently during spaceflight, individual urine voids are collected into urine collection devices, but the existing method has key limitations, including the amounts of crew time required, mass to launch, and trash to return, and loss of urine for recycling and water recovery.

In 2014, the ISSMP proposed a challenge through the NASA@Work platform, seeking to identify innovative methods for measuring urine volume in real time during flight, while maintaining the capability to take samples for return to Earth and to recycle urine. NASA@work fosters collaboration within the NASA community through the submission of solutions to posted challenges.



The design submitted to the NASA@work challenge allows for the collection of a research sample before the remaining urine is recycled into potable water.

Among the many submissions was a unique technology, the Microgravity Graduated Cylinder, submitted by a collaborative team from the JSC Crew and Thermal Systems Division and investigators from the Capillary Flow Experiments (CFE). The CFE demonstrated how liquids behave in space, the effects of capillary forces, how differently shaped containers change the behavior of a fluid, and how these actions can be used to passively separate liquids and gases.

This technology relies on capillary action to capture the urine and the volume can be visually measured. The system allows the collection of a research sample before the remaining urine is recycled into potable water. There are no moving parts, sensors, calibration or power requirements, and no maintenance other than a flush after use. The prototype was produced using a 3-D printer, making it ideal for the spacecraft environment. This novel technology will continue to be developed and may lead to a technology demonstration aboard the ISS.

FLIGHT ANALOGS PROJECT

During FY2014, significant progress was made with ongoing bed rest studies. The Countermeasure and Functional Testing 70-day bed rest study, initiated in 2012, is complete. This study, composed of eight individual research studies—each with its own aim—operated as one integrated research campaign. This structure maximizes the scientific return from one group of test subjects, and minimizes the total amounts of resources required.

In addition, a new bed rest study requiring 18 subjects was initiated in FY2014. This study's aim is to examine the roles of vascular compliance and increased dietary intake of sodium in the visual impairment syndrome. Older and younger subjects will undergo 14 days of head-down-tilt bed rest.

Within each of these groups, two subgroups of subjects will be exposed to a diet with lower or higher salt content. Results from this study will show how increased dietary sodium and vascular compliance are linked to changes in eye structure and function.

FY2014 Investigations at the FARU and Continuing into Fiscal Year 2015

Investigation Title	Investigator and Institution	Subject Requirements		
		Required N	Completed through FY2014	Planned for FY2015
Physiological Factors Contributing to Post-flight Changes in Functional Performance: Bed Rest Analog Study (FTT)	Jacob Bloomberg, PhD *NASA/JSC*	24	21	3
Integrated and Resistance and Aerobic Training Study - Bed Rest (iRATS)	Lori Ploutz-Snyder, PhD *USRA*	24	21	3
Testosterone Supplementation as a Countermeasure against Musculoskeletal Losses during Space Exploration	Randall Urban, MD *UTMB*	24	24	Completed
Effects of Retro Nasal Smelling, Variety, and Choice on Appetite and Satiety	Jean Hunter, PhD *Cornell University*	16	16	Completed
Bed Rest as a Spaceflight Analog to Study Neurocognitive Changes: Extent, Longevity, and Neural Bases	Rachael Seidler. PhD *Univ. of Michigan*	16	16	Completed
Automated Detection of Attitudes and States through Transaction Recordings Analysis (AD ASTRA) Bed Rest Analog	Christopher Miller, PhD *Smart Information Flow Technologies*	15	12	3
Integrated and Resistance and Aerobic Training Study - Bed Rest (iRATS) with Flywheel	Lori Ploutz-Snyder, PhD *USRA*	8	5	3
FAP Standard Measures	Ronita Cromwell, PhD *USRA*	N/A	13	Collected on all long-duration subjects
Vascular Compliance	Steven Platts, PhD *NASA/JSC*	18	4	16

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FY2014 Investigations Conducted in HERA and NEEMO 18

Investigation Title	Investigator	NEEMO	HERA Mission 1
Measuring, Monitoring, and Regulating Teamwork for Long Duration Missions	Steve Kozlowski, PhD *Michigan State Univ.*	X	X
Optical Computer Recognition of Stress, Affect and Fatigue in Space Flight	David Dinges, PhD *Univ. of Pennsylvania*		X
AD ASTRA: Automated Detection of Attitudes and States through Transaction Recordings Analysis	Christopher Miller, PhD *Smart Information Flow Technologies*		X
Protocols for Asynchronous Communication in Space Operations: Communication Analyses and Experimental Studies	Ute Fischer, PhD *Georgia Institute of Technology* Kathleen Mosier, PhD *San Francisco State Univ.*	X	X
Cognition	Mathias Basner, MD, PhD, MSC *Univ. of Pennsylvania*		X
Using Real-Time Lexical Indicators to Detect Performance Decrements in Spaceflight Teams: A Methodology to Dynamically Monitor Cognitive, Emotional, and Social Mechanisms that Influence Performance	Eduardo Salas, PhD *Univ. of Central Florida*	X	X
Evaluation of an Objective Behavioral Assay of Group Cohesion	Peter Roma, PhD *Institute of Behavior Resources*	X	X
Composing and Developing Resilient, Adaptive and Self-Sustaining Teams for Long Duration Space Exploration	Scott Tannenbaum, PhD *The Group for Organizational Effectiveness*	X	X
Sensorimotor Assessment and Rehabilitation	Michael Schubert, PhD *Johns Hopkins University*	X	X
Habitability Assessment of International Space Station	Sherry S. Thaxton, PhD *Lockheed Martin*	X	X
Evaluation of the ISS Food Tracker (ISS FIT) App	Sarah Zwart, PhD *USRA*		X
Dose Tracker Application for Monitoring Crew Medication Usage, Symptoms and Adverse Events During Mission	Viginia E. Wotring, PhD *USRA*		X

Completion of HERA Campaign One: Four 7-Day Immersive Analog Missions

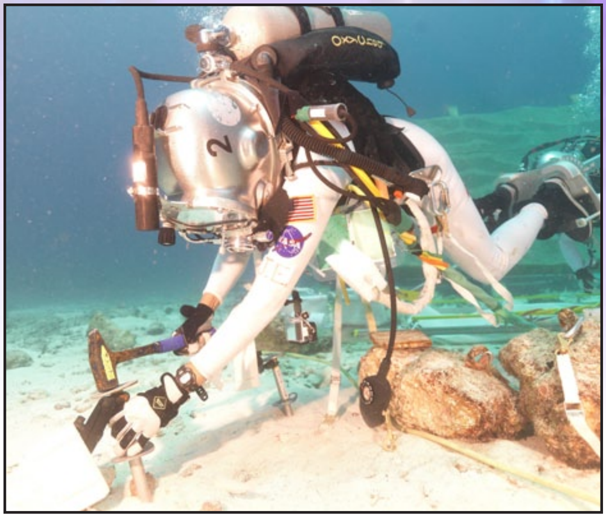
In FY2014, FAP completed its first HERA campaign, which encompassed 12 studies that were integrated into four 7-day missions. The HERA was acquired by HRP in 2013 to enable research in an isolated and confined environment. Studies included in these missions examined teamwork, habitability, stress, fatigue, psychological and cognitive state, communication delays, and sensorimotor function, and validated dietary and pharmacological tools.

Each HERA mission was crewed by four subjects who participated in a high-fidelity, immersive spaceflight analog mission. Crewmembers were assigned typical flight crew positions of commander, flight engineer and mission specialists. The mission simulated the work pace and operations of the ISS and other conditions that would be expected during a long-duration exploration mission.

NEEMO-18 Provides Opportunity for Comparison with HERA Analog

In FY2014, FAP supported research operations during NASA Extreme Environments Mission Operations (NEEMO)-18. The 9-day mission was conducted 62 feet below the ocean surface in Florida International University's Aquarius Reef Base undersea research habitat off the coast of Key Largo. The crew of four was led by a mission commander from the Japan Aerospace Exploration Agency and also included representatives from NASA and the European Space Agency.

Utilizing a subset of the HERA research complement, NEEMO-18 offered HRP the unique opportunity to perform a cross-analog comparison of HERA and NEEMO. This comparison will offer insight into the similarities and differences between these two unique analogs, and the results will be used to guide the future implementation of HRP research.



NEEMO is an extreme, isolation analog where crewmembers live and work 62 feet below the surface of the sea off the Florida Coast in the Aquarius habitat.

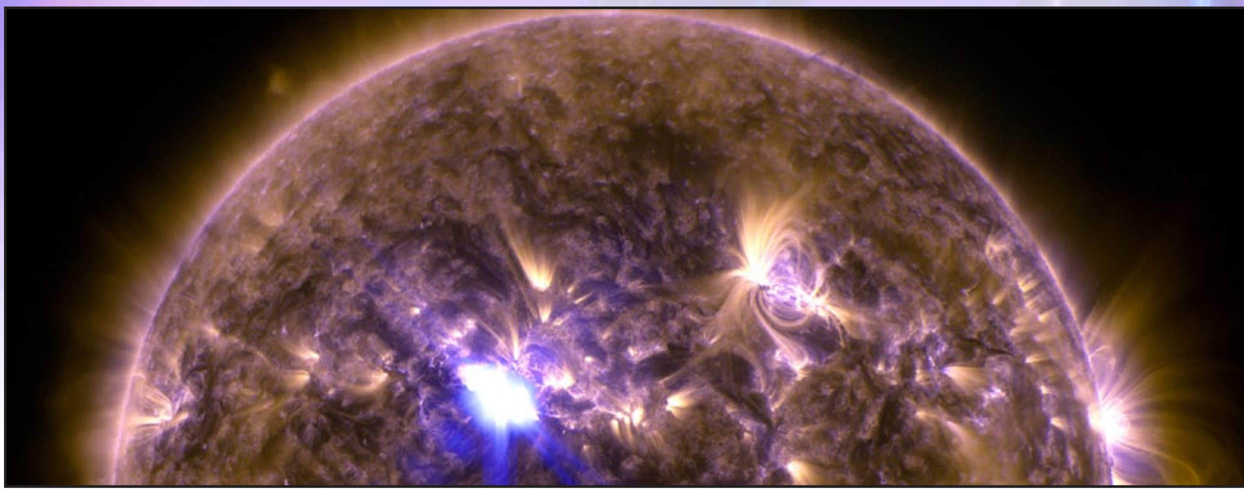
FUTURE PLANS

In the next few years, HRP and FAP will continue utilizing analog facilities to conduct human research. Not all research can be done in an analog setting; therefore, finding appropriate analogs for conducting research is an important task for FAP.

December 2014 will mark the conclusion of HRP's support of the Flight Analog Research Unit at the University of Texas Medical Branch. Instead, HRP will support more multi-lateral analog campaigns. The FAP is assessing several new facilities including several Antarctic sites, the :envihab facility in Germany, and the Nazemnyi Experimentalnyi Komplex (NEK)—a Russian isolation facility.

The :envihab facility offers several unique capabilities, such as controlled carbon dioxide delivery systems, which may provide a key to understanding the vision impairment syndrome, a large environmental chamber and a short-radius centrifuge that can be utilized in many different research areas. Additionally, the HERA will continue to play an important role in HRP research, and Campaign 2, which consists of 14-day missions, begins in FY2015.

SPACE RADIATION ELEMENT



SPACE RADIATION

Overview

The goal of the Space Radiation Element is to ensure that crewmembers can safely live and work in space without exceeding acceptable radiation health risks. Space radiation differs from radiation encountered on Earth. The main sources of space radiation are galactic cosmic rays (GCRs), trapped particles that consist of protons and electrons trapped in Earth's magnetic field, and solar particle events (SPE). GCRs permeate interplanetary space and include high-energy, charged nuclei of elements ranging from hydrogen to iron.

At the cellular and tissue levels, these heavy ions cause damage that is largely different from the damage caused by terrestrial radiation, such as X-rays or gamma-rays, because of their significantly greater ionizing power. Because of this difference, there are large uncertainties in quantifying biological response. Shielding against GCRs is much more difficult than shielding against terrestrial radiation because of the large masses required to stop primary GCR particles in space and the secondary particles generated in the shield material.

Health risks from space radiation may include an increased incidence of cancer, acute radiation syndrome, degenerative tissue damage manifested as health problems such as heart disease and cataracts, and early and late central nervous system (CNS) damage. Cancer risks pose the largest challenge for exploration. The uncertainties in cancer risk projection have large impacts on exploration mission designs, and they can affect NASA's ability to accurately assess mitigation measures such as shielding and biological countermeasures. There are also uncertainties about the dose thresholds, effects of radiation quality, and latency and progression rates for risks involving the CNS and cardiovascular system, that will affect mission designs. Finally, research is needed to optimize radiation protection practices and countermeasures to prevent acute radiation syndromes from SPE.

The results of space radiation studies contribute to human exploration by providing a scientific basis to accurately project and mitigate health risks from space radiation. Research in radiobiology and physics guides and supports risk assessment and protection strategies. The results will provide tools for evaluating shielding recommendations for habitats and vehicles, as well as requirements for storm shelters and early warning systems for SPE. To read more about the Space Radiation Element, please visit: http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-srpe.html.

FY2014 Activities and Accomplishments

The Space Radiation Element completed another successful year of high-quality, hypothesis-driven research through the efforts of many investigators across the country. Numerous experiments were conducted at the NASA Space Radiation Laboratory (NSRL) with the support of a dedicated science staff. The 25th Annual NASA Space Radiation Investigators' Workshop included the formation of virtual working groups of principal investigators to enhance the sharing and discussion of scientific research results.

New research and investigators were selected and funded from respondents to a NASA Research Announcement to conduct studies in understanding and mitigating the risks of cancer, cardiovascular disease, and in-flight and late CNS effects from exposure to space radiation. Additionally, new NASA Specialized Centers of Research (NSCOR) will be selected in FY2015. An NSCOR grant differs from an individual grant award in that it incorporates a number of complementary research projects that focus on a single research area.

Collaborative efforts with the Behavioral Health and Performance and the Human Health and Countermeasures Elements, continued to improve our knowledge about the combined effects of spaceflight radiation on the CNS, which affected behavior, and on the risk of developing cardiovascular disease. In addition, efforts are underway to promote sharing of samples that have already been irradiated, collected, and stored at our various principal investigators' institutions, to enhance scientific output.

NSRL Beam Runs Continue to Provide Insight into the Space Radiation Environment

The NSRL is a state-of-the-art facility managed by Space Radiation (SR) at the Brookhaven National Laboratory located on Long Island, New York. The NSRL uses beams of high-energy heavy ions to simulate a typical space radiation environment and SPE, making it one of the few places in the world where investigators can conduct ground-based research in space radiobiology, shielding, and dosimetry. In FY2014, principal investigators funded by SR participated in three campaigns at the NSRL. During these campaigns, nearly 50 investigator teams conducted experiments to irradiate more than 13,000 biological specimens, including tissues and cells, with the facility providing more than 1,000 hours of beam time. The results of these investigations are published in over 75 peer-reviewed articles in major journals such as *Cancer Research*, *Oncogene*, *Radiation Research*, *Stem Cells*, *Clinical Cancer Research*, and *Neurology*.

Researchers at the NSRL are preparing a biological sample for irradiation within the beam line.

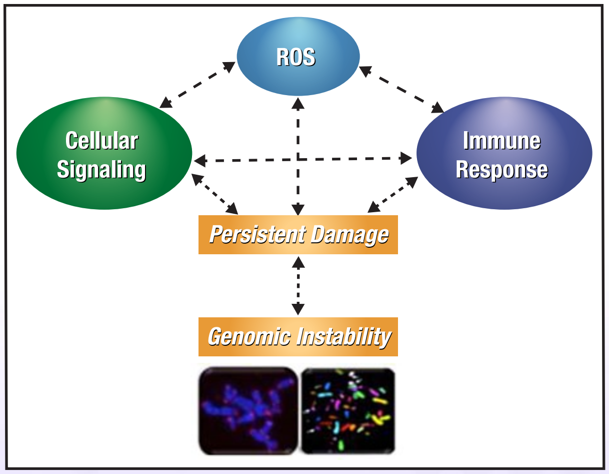
In particular, results of NSCOR studies on solid tumors induced by space radiation continue to suggest that differences in tumorigenic potential exist between the high-linear energy transfer (LET) heavy ions found in space and terrestrial low-LET gamma- or X-rays. New data shows distinctions in genomic, proteomic, and metabolomic profiles elicited by heavy-ion exposure compared to gamma-rays in cell and tissue models. These distinctions provide insights important for risk modeling and future identification of risk biomarkers.

In addition, further evidence emerged for nonlinear responses at low doses, resulting from non-targeted effects. These responses may confound conventional paradigms and estimates of the relative biological effectiveness of heavy ions compared to gamma-rays. Evidence related to potential in-flight or acute CNS effects due to space radiation exposure supports the idea that exposure to space radiation results in relatively long-term decreases in the production of adult neurons in the hippocampus brain region in mouse models. Although the significance of these results to the morbidity of astronauts has not been determined, decreases in the production of neurons in the adult general population have been linked to functional deficits in learning, memory, and mood, and it remains to be determined how chronic low-dose-rate exposures to heavy ions will affect this process.

Radiation Science Working Groups Enhance HRP Scientific Output

In addition to individual investigators and NSCORs, the Space Radiation Element uses collaborative working groups to discuss and share current scientific research results. Three working groups: the Cancer Biology Working Group, the Hematologic Cancer Working Group, and the Virtual Systems Biology Modeling team, were active this year. These working groups enhance the scientific output of selected grants, NSCOR, and the HRP as a whole.

Interaction between groups is facilitated at the annual HRP Investigators' Workshop, where each group reports their progress. The working groups held focused discussions on radiation biology which encompassed



Modeling teams consider the possibility of strong links between different cellular responses which may potentiate persistent damage and genomic instability.

broad issues related to experimentation, experimental models, systems biology, modeling, murine cancer models, and extrapolation to human risk. These topics have long-range implications for the field and inform NASA's evaluation of human risk due to space radiation exposures.

The Hematologic Cancer Working Group is specifically focused on understanding the risks of hematologic malignancies from space radiation exposure. They also discuss topics relevant to radiogenic leukemia risk assessment which includes target cell identification, stem cell kinetics, model systems, and cytogenetic and molecular lesions. The Virtual Systems Biology Modeling team is focused on understanding cancer development processes after exposure to space radiation and the roles of reactive oxidative stress, DNA damage repair, and inflammation. The Central Nervous System Working Group will be formed in FY2015 to consider in-flight and late effects on astronauts' behavior and performance from exposure to the heavy ions found in space.

Board Gives Concurrence on Space Radiation Permissible Exposure Limits (PEL)

To keep space radiation exposure standards updated, the Space Radiation Element presented an informational briefing to the NASA Human Systems Risk Board on the status of the 30-day and yearly space radiation permissible exposure limits (PELs) to the blood-forming organs (BFO) and skin. Based on results from the NSBRI Center for Acute Radiation Research (CARR), presenters provided updated research results pertaining to the risk of acute radiation syndromes due to SPE. Specifically, they focused on the accuracy of the current PEL of 250 mGy-Eq to the BFO, and the validity of the current PEL of 1500 mGy-Eq for the skin. These limits are intended to protect astronauts from acute radiation syndromes, including the prodromal risks of nausea, vomiting, anorexia, and fatigue; alterations to the hematopoietic system; and skin injury resulting from exposure to a large SPE.

The board concurred that no changes to the short-term PELs for the BFO and skin were recommended at the current time. Future plans are to conduct an external review of the major research results related to the short-term PELs upon completion of the research by the NSBRI's newly established Center for Space Radiation Research (CSRR). Future provision of status or recommendations for exposure limits will be based on results of the external review.

NSBRI Establishes New Center for Space Radiation Research (CSRR)

In August of 2013, NSBRI released the Request for Applications (RFA) for the establishment of the NSBRI CSRR to address the acute and degenerative tissue effects on living systems after radiation exposures which model space radiation beyond low Earth orbit (LEO). The RFA for the CSRR was based on Standing Review Panel recommendations and was crafted in partnership with Space Radiation.

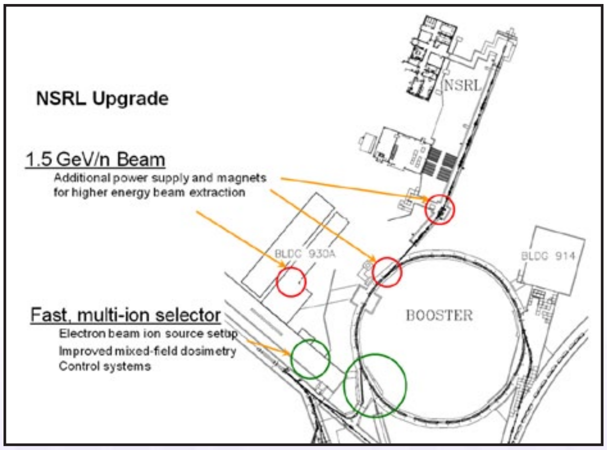
The 3-year, $6 million grant was awarded in July 2014 to Dr. Marjan Boerma, an Associate Professor of Pharmaceutical Sciences at University of Arkansas for Medical Sciences (UAMS). Dr. Boerma, also a member of the College of Pharmacy Division of Radiation Health, will direct a team of investigators at four U.S. institutions to implement the mission of the CSRR. The CSRR is tasked with quantifying degenerative tissue effects—specifically cardiovascular outcomes—after exposures to radiation that closely model the radiation environment expected for exploration-class missions. The research studies, outcomes, and deliverables of the CSRR will feed into risk models to help mitigate degenerative and acute radiation risks for astronauts on exploration missions.

FUTURE PLANS

To continue with the cutting-edge ground-based research being conducted through the Space Radiation Element, major upgrades to the NSRL are under way. The Galactic Cosmic Ray Simulator Project at the NSRL will generate an accelerator-based spectrum of ions and energies that closely approximate those that are known to make up the shielded GCR environment in space. These upgrades will enhance the ability to simulate the primary and secondary space radiation environment with a mixed-field, high-energy capability planned for completion in late 2016.

Plans include the ability to produce a rapidly switchable ion source capable of delivering 6 to 12 ion species to the experimental area. Magnets in the beam line will also be upgraded to deliver beams at 1.5 GeV/nucleon to better represent the energies in the natural GCR. A reference field will be defined to include the rapid switching of H, He, O, Si, and Fe ions over multiple energies and to use well-designed absorbers. To date, the laser ion source that generates ions for acceleration has been installed and is currently being used.

The facility modifications for high-energy research up to 1.5 GeV per nucleon will be completed in FY2015. Additionally, the modifications of controls to enable rapid switching between ion species will be completed and tested in FY2017. More detailed descriptions of the field characteristics will be made available on the NSRL website as the upgrades progress.



A 1.5 GeV/n beam and fast, multi-ion selector are upgrades planned for the NSRL within the next several fiscal years.

SPACE RADIATION

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HUMAN HEALTH COUNTERMEASURES ELEMENT

Overview

NASA uses the term "countermeasures" to describe the strategies to keep astronauts healthy and productive during space travel and return to Earth. The Human Health Countermeasures (HHC) Element is responsible for understanding the normal physiologic effects of spaceflight and developing countermeasures to those with detrimental effects on human health and performance. HHC provides the biomedical expertise for the development and assessment of medical standards, vehicle and spacesuit requirements, and countermeasures that ensure crew health during all phases of flight.

Preflight countermeasures involve physical fitness and exercise, and physiologic adaptation training. In-flight countermeasures include nutritional health, physical fitness, pharmaceuticals, and sensorimotor training protocols. Postflight countermeasures target rehabilitation strategies. Before they are flight-tested, candidate countermeasures and technologies are developed and refined using ground-based studies.

The HHC is composed of five portfolios: Vision and Cardiovascular, Exercise and Performance, Multi-System, Bone and Occupant Protection, and Technology and Infrastructure. To learn more, please visit: http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-hhc.html.

VISION AND CARDIOVASCULAR PORTFOLIO

FY2014 Activities and Accomplishments

The research tasks managed by the Vision and Cardiovascular Portfolio address the risks of orthostatic intolerance during re-exposure to gravity, cardiac rhythm problems, and spaceflight-induced intracranial hypertension and vision alterations. The orthostatic intolerance risk is now considered partially controlled by countermeasures. The cardiac rhythm risk is being reevaluated in light of new evidence from the Integrated Cardiovascular study, among others.

HHC continues to aggressively pursue understanding of the spaceflight-induced intracranial hypertension/vision alterations risk. A variety of studies evaluating changes in the eye, brain, and cardiovascular system are expected to address this complex risk.

Potential Discovery of Genetic Relationship to Spaceflight-Induced Vision Issues

Preliminary findings from ISS crewmembers participating in the Nutritional Status Assessment experiment identified a potential link between nutritional biochemistry and vision problems experienced by some astronauts. Dr. Scott Smith from JSC and his team found increased concentrations of four metabo-

HHC

lites in the blood of astronauts with vision issues. These metabolites are associated with a metabolic pathway known as the "one-carbon metabolism pathway." The biochemical differences in astronauts with vision issues were present not only during flight, but also before flight. This led the investigator team to propose that genetic differences, or polymorphisms, might be part of the explanation for some crewmembers having vision issues while others did not.

A follow-up study was conducted to evaluate genetic differences in the one-carbon pathway, and to ascertain how these relate to vision and eye exams. Nearly all astronauts from Expeditions 1-48 agreed to participate in the study. Biochemical and statistical analyses continue, but the preliminary data is striking. Repeated biochemical analyses confirm that astronauts experiencing vision issues had higher concentrations of metabolites related to the one-carbon pathway.

Furthermore, preliminary evaluation of the genetic data indicates that all of the crewmembers with one specific polymorphism had vision issues to one degree or another. Put another way, of crewmembers who did not have vision issues, none of them had this particular genetic polymorphism. However, not everyone who had vision issues had this genetic polymorphism, so the situation is more complex than the involvement of this single polymorphism.

Analyses continue, and investigators hope to bring more clarity in the coming year. The implications of this research for NASA, along with the broader medical and scientific communities, could be profound.

New Study Promotes Collaboration Between U.S. and Russian Space Agencies

In 2015, the Fluid Shifts study will become one of the most comprehensive spaceflight experiments in the history of HRP. This study is HRP's first fully integrated U.S.-Russian in-flight investigation, with crewmembers from NASA and the Russian Federal Space Agency, "Roscosmos." The investigator team

A Fluid Shifts test subject undergoes head-down tilt while wearing the Chibis, a Russian lower body negative pressure (LBNP) device. In the foreground, a researcher collects Optical Coherence Tomography (OCT) imagery of the retina.

includes Dr. Michael Stenger from Wyle Laboratories in Houston, Dr. Scott Dulchavsky from the Henry Ford Hospital in Detroit, and Dr. Alan Hargens from the University of California, San Diego.

This study will be a model for future unified international biomedical research endeavors. The initial subjects will be the first "one-year mission" ISS crewmembers. Roscosmos' involvement in this study extends far beyond the use of its crewmembers as test subjects. For the first time, U.S. research operations on the ISS will take place within the Russian Orbital Segment (ROS) with collaborative use of Russian and U.S. hardware. This represents the first time since the NASA-Mir Program in the 1990s that a joint NASA-Roscosmos biomedical research program has existed.

The full name of the study, "Fluid shifts before, during and after prolonged spaceflight and their association with intracranial pressure and visual impairment," only hints at the project's extensive research scope, which resulted from the merger of three separately funded investigations. Ocular changes have been observed in returning crewmembers, and spaceflight-induced elevation of intracranial pressure has been hypothesized to cause these changes. The study will shed light on the role that in-flight body fluid redistribution plays in these phenomena. Importantly, this study will investigate the ability of lower-body negative pressure (LBNP) to reverse the effects of the headward fluid shift. Currently the Russian *Chibis*, an LBNP device located inside the ROS, is the only ISS hardware available for this purpose.

Four Year ISS Cardiovascular Study Details the Effects of Spaceflight on the Heart

The Integrated Cardiovascular (ICV) study, lead by Dr. Benjamin Levine from the University of Texas Southwestern Medical Center at Dallas and Dr. Michael Bungo from University of Texas Medical School in Houston, concluded this year after four years on the ISS. The study investigated whether heart muscle would atrophy during long-duration spaceflight, whether the structure or performance of the heart would be affected, and whether these changes might predispose astronauts to rhythm abnormalities. Study data substantiated the well-described loss of circulating blood volume reflected as a change in cardiac filling. The heart also became more spherical. Detailed measures of diastolic function and myocardial strain demonstrated that cardiac function was preserved.

Each crewmember participated in an intense exercise program while onboard the ISS, such that ICV was as much a validation of this countermeasure as it was a characterization of the uninhibited response to spaceflight. In fact, ICV showed that the change in the work the heart did in space relative to the work done on Earth correlated directly with how much mass the heart lost or gained during the mission.

Cardiac rhythm disturbances were seen during previous spaceflights and during ICV. With rigorous monitoring, it was shown that the magnitude of extra heart beats differed greatly between crewmembers but that the total number of these appeared similar in an individual whether on the ground or in space.

Each subject received intravenous saline solution immediately after landing. Subsequent testing demonstrated that crewmembers' cardiovascular systems were able to tolerate simulated martian gravity without detriment. Overall, ICV has provided one of the most comprehensive descriptions of the human heart during long-duration spaceflight.

A crewmember prepares to use the Integrated Cardiovascular (ICV) Resting Echo Scan in the ISS Columbus laboratory.

Integrated VIIP Research Plan Encompasses 70 Studies to Address Significant Risk

The Visual Impairment Intracranial Pressure (VIIP) syndrome is NASA's number-one human spaceflight risk. The syndrome, which is related to microgravity exposure, manifests with changes in visual acuity and eye structure. In some cases, elevated cerebrospinal fluid pressure has been documented post flight, reflecting increased intracranial pressure (ICP).

The operational and research communities at NASA are working collaboratively in an effort to understand the mechanisms causing the VIIP syndrome and to provide mitigation and countermeasures. Crewmembers undergo extensive pre-, in-, and postflight testing, and HHC has established the VIIP Research Project. This integrated research plan covers four identified knowledge gaps and encompasses more than 70 studies. About 25 VIIP studies are currently in progress and 5 have been completed. Ongoing studies include: data mining, animal analogs, bed rest and other human microgravity analogs, computer modeling, technology development and flight certification, and in-flight studies involving crewmembers. These studies aim to understand the impact of the microgravity environment on the eye, the cardiovascular system, and the central nervous system.

In FY2014, the main flight experiment was the Ocular Health study, an investigation that seeks to identify underlying mechanisms and define the timeline for the appearance and resolution of symptoms. This important study is lead by Dr. Christian Otto from Universities Space Research Association in Houston.

EXERCISE AND PERFORMANCE PORTFOLIO

FY2014 Activities and Accomplishments

HHC's Exercise and Performance Portfolio addresses risks such as a crewmember's impaired control of the spacecraft and their immediate vehicle egress due to sensorimotor alterations associated with spaceflight. Additionally, the Portfolio addresses the risk of reduced physical performance due to diminished aerobic capacity and impaired performance due to reduced muscle mass, strength, and endurance.

In FY2014, the Functional Task Test study finished data collection while the Field Test study began. These studies are essential to understanding crew capabilities immediately after landing, and they inform future countermeasure development and validation. Finally, the Exercise and Performance Portfolio continues to share exercise outcome measures with stakeholders in the ISS and exploration community, transitioning research findings to operations.

Functional Task Test Study Complete

The goals of the Functional Task Test (FTT) study, led by Dr. Jacob Bloomberg from JSC, were to determine the ability of a crew to perform physical tasks typically found in exploration-class missions and the impact of microgravity on their performance. Furthermore, the study seeks to identify the physiological factors that contribute to these decrements in performance. Microgravity causes adaptations in multiple systems, including the musculoskeletal, cardiovascular, and sensorimotor systems. These adaptations might affect a crewmember's ability to perform critical tasks immediately after landing on a planetary surface.

An Functional Task Test (FTT) subject performs the ladder climb task while instrumented with monitoring equipment. Other tasks include hatch opening and obstacle avoidance.

In FY2014, the FTT Project completed data collection on 13 ISS crewmembers. The same physiological measures were also collected on 28 ground-based subjects in a complementary 70-day head-down-tilt bed rest. The bed rest analog was used to investigate the impact of 'body unloading' on functional tasks and the underlying physiological factors that lead to decrements in performance. This data was then compared with results obtained in the spaceflight study.

The testing protocol included assessing functions such as ladder climbing, hatch opening, egress and obstacle avoidance, and recovery from a fall. Physiological measures included assessments of postural and gait control, visual acuity, fine motor control, orthostatic intolerance, and upper- and lower-body muscle strength.

Preliminary study data suggests that tests requiring a greater demand for dynamic control of postural equilibrium—such as fall recovery or obstacle avoidance—showed the greatest decrement in performance. Tests with reduced requirements for postural stability—such as hatch opening, ladder climb, or manual manipulation of objects—showed less reduction in performance. The data points to the importance of providing significant axial body loading

HHC

during in-flight treadmill and resistive exercise, along with preflight and in-flight balance training.

The information obtained from this study will be used to design countermeasures that specifically target the physiological systems most responsible for the altered functional performance associated with spaceflight. A final report will be submitted in FY2015.

New Field Test Study Begins Data Collection Immediately After Vehicle Egress

Crewmembers experience alterations in multiple physiological systems due to spaceflight. Changes include sensorimotor disturbances, cardiovascular deconditioning, and loss of muscle mass and strength. These disruptions may cause significant impairments in performance of tasks immediately after landing when a crewmember is reintroduced to a gravitational environment after prolonged travel in weightlessness. An example of which would be exiting the spacecraft without assistance as would be expected after landing on a planetary surface during an exploration-class mission.

Historically, initial data collection after a mission was delayed until the second day after landing. Thus, neither the immediate response after landing, nor a true characterization of the entire recovery time constant, have been investigated or established for long-duration flights.

The Field Test study represents a joint effort between Dr. Milard Reschke of the Neuroscience Laboratory at JSC and Professor Inesa Koslovskaya from the Sensorimotor Laboratory at the Institute of Biomedical Problems in Moscow, Russia. The study's primary goal is to determine functional task performance representative of critical mission requirements that crews must perform after landing following long-duration missions.

A secondary goal is to evaluate a new gradient compression garment and compare it with the traditional Russian *Kentavr* garment. A battery of functional performance tasks are being conducted on crewmembers, beginning as soon after landing as possible with two follow-up measurements on the day of landing.

The Field Test study marks the first time data is collected immediately after landing. Crewmembers are taken into a tent which is quickly erected near the Soyuz landing site.

Study data collection begins immediately after landing and continues until a crewmember's full functional sensorimotor and cardiovascular responses have returned to preflight normal values. This typically occurs about 30 days after landing. These early measurements will make it possible to establish a recovery time constant for functional performance, not previously captured in over 50 years of spaceflight. Findings from this investigation will provide the information needed for planning future Mars or other deep-space missions with unassisted landings.

ISS Exercise Outcomes Presented to Human System Risk Board (HSRB)

Exercise continues to be the main countermeasure used during missions to prevent loss of cardiovascular and musculoskeletal fitness. Crew medical data are used to monitor the effectiveness of standard exercise programs and to guide recommendations for future research. HRP also supports operational research such as the Integrated Resistance and Aerobic Training Study (SPRINT) and VO_2max studies.

HHC

The VO_2max study demonstrated the limited accuracy of the current on-orbit estimation of aerobic capacity. Furthermore, data from actual VO_2max measurement suggests the need for revision of the on-orbit medical test. Combined data from SPRINT and VO_2max demonstrates that high-intensity exercise can maintain aerobic capacity over a six-month ISS mission, and that it is possible to improve aerobic fitness after an initial loss during flight.

Currently very few crewmembers maintain their aerobic capacity and about 15% fall below NASA's standard, which states that the loss of aerobic capacity should not exceed 25%. Future HRP research will focus on optimizing exercise programs to reduce variability among crewmembers, thereby increasing confidence that all crewmembers are protected on exploration-class missions.

Muscle performance is not easily evaluated on the ISS. HRP has developed a novel method of assessing thigh and calf muscle volume using ground-guided in-flight ultrasound that is currently in use on the ISS as part of the SPRINT study. Additionally, researchers are evaluating the use of portable load-monitoring technologies for use with the advanced resistive exercise device (ARED). The ability to quickly and accurately measure ARED loads would enhance operational research designed to determine what loading profiles are optimal for the maintenance of muscle performance. Bed rest research is making progress toward such answers and has already shown that the muscles of the calf are much harder to protect than those of the thigh. These research results will provide guidance on how to better train skeletal muscle.

A SPRINT crew participant completes an exercise session on the ISS 2nd generation treadmill (T2).

Currently about 25% of crewmembers are not meeting the NASA Health and Fitness Standard, which designates no more than 20% loss of strength. Isokinetic strength data shows it is possible to maintain and even improve strength during a 6-month mission. However, in terms of aerobic capacity, there is a need to understand how to extend these positive outcomes to more crewmembers.

Next steps include refinement of the intensity, frequency, and duration of exercise to maximize results for all crewmembers, as well as matching fitness parameters with performance on exploration mission tasks. This would allow refinement of NASA fitness standards for exploration, define requirements for exercise hardware, and allow development of readiness tests of performance on exploration missions.

MULTISYSTEM PORTFOLIO

FY2014 Activities and Accomplishments

The Multisystem Portfolio encompasses a diverse group of disciplines, including nutrition, immunology, pharmacology, extravehicular activity (EVA), and decompression sickness (DCS). Each discipline team strives to understand normal effects of spaceflight and develop countermeasures to detrimental effects on human health and performance.

During FY2014, investigators completed important work to both the scientific and medical communities by characterizing spaceflight-induced immune and nutritional status changes. The study "Validation of Procedures for Monitoring Crewmember Immune Function," led by Dr. Clarence Sams, assessed and validated procedures to monitor immune function and dysregulation that occurs during spaceflight. The "Nutrition Status Assessment Supplemental Medical Objective" study, also known as the Nutrition SMO led by Dr. Scott Smith from JSC, completed all data collection and is finalizing analysis. Pharmacology investigators began developing "Dose Tracker," an app for the iPad that will collect in-flight medication usage data and correlate it with possible changes in efficacy that may occur during spaceflight.

Extensive ISS Nutrition Study Complete; Provides Valuable Data to NASA Community

The Nutrition SMO study began in 2006 and was later expanded to include in-flight blood and urine collections and additional biochemical markers. Data from this experiment provides a valuable resource of pre-, in-, and postflight biochemical data, including data related to vitamin and mineral status, bone and protein chemistry, inflammation, oxidative damage, endocrinology, and general chemistry. Volumes of data have been provided to the Life Sciences Data Archive, and have been indispensable in decision-making by flight surgeons, HRP management, and ISS Program management. The knowledge revealed by the Nutrition SMO also contributes to the general medical and scientific communities. The final frozen samples were returned from the ISS on SpaceX-3 in 2014, and final analyses are underway.

To date, ten manuscripts have been produced from the available data. Perhaps most notable, data from the Nutrition SMO provided evidence that one-carbon metabolism is altered in crewmembers who have experienced vision changes and other medical changes in the eye after long-duration spaceflight.

Study data also documents the effectiveness of the ARED in preserving bone mineral density, and the impact of the device on bone metabolism. In FY2014, data were published documenting that no differences between men and women were observed with respect to bone loss or risk of kidney stones on ISS missions.

Mike Lopez-Alegria collects a blood sample on the ISS in 2006 as part of the Nutrition SMO study. The collection tubes seen on the left are then stored in a freezer until returned to ground.

The investigator team also published evidence that an increased amount of iron in the body early in flight is related to oxidative damage to body tissue, and also to the amount of bone loss in some bone regions. The data also showed that testosterone and related hormones are unchanged by real or simulated weightlessness. These observations contradict earlier findings from a previous limited data set which suggested that testosterone levels are reduced during spaceflight.

50 Years of Human Space Travel: Implications for Bone Calcium Research Published

A team of NASA and extramural scientists worked together on an article reviewing the history of calcium and bone research related to human spaceflight. Published in the 2014 *Annual Review of Nutrition*, the article reviews research findings from spaceflight and analog environments, and focuses on the interrelationship of calcium metabolism, bone biochemistry, and bone health.

The article highlights the history of bone and calcium findings from spaceflight, including the many attempts at physical, pharmacological, and nutritional countermeasures against bone loss. It expands upon recently published Nutritional Status Assessment data showing that good nutrition, including energy intake and vitamin D status, and heavy resistance exercise can mitigate changes in bone mineral density during spaceflight.

Many of the authors of the review were part of the team studying calcium kinetics on the Space Shuttle STS-107/Columbia mission in 2003, and homage to that crew is included in the paper, as well as some details of the experiment conducted on that tragic mission. The review also includes a look at nutrition research needed to make human exploration possible, noting, “Optimal nutrition along with exercise countermeasures play a significant role in maintaining and protecting bone. In particular, ensuring optimal energy and calcium intakes, minimizing sodium and iron intakes, and enhancing consumption of omega-3 fatty acids and vegetable protein are all important components of a healthful space diet.” The planned Integrated Nutrition study will be an important agent in moving optimal space nutrition forward.

Data Mining Effort Produces Hypobaric DCS Treatment Model

Data from hypobaric research exposures from 1983 to 2014 was mined for relevant information about decompression sickness (DCS) symptom resolution to create the Hypobaric DCS treatment model. The data consisted of 154 cases of hypobaric DCS symptoms with ancillary information from tests on 56 men and 18 women.

An EVA Physiology Scientist monitors a test subject in the Hypobaric Chamber at JSC. Exploration-class missions have limited resources and DCS mitigation is important.

This model links a decrease in the computed blood gas bubble volume to the probability of DCS symptom resolution while accounting for multiple symptoms in the same subject. The model describes how available resources for exploration missions such as increased pressure, oxygen and time, can be used to resolve DCS symptoms in lieu of the standard-of-care treatment, which requires a hyperbaric chamber.

NASA has always operated with a strategy of preventing DCS through validated denitrogenation protocols rather than treating symptoms. To date, no cases of DCS have been reported during EVA, which is a huge success. Given this low probability of DCS and the capability for prompt treatment of a symptom with guidance from the model, it is likely that any DCS symptom and resulting blood gas phase will resolve with available resources and minimal impact on astronaut health, safety, and productivity.

BONE AND OCCUPANT PROTECTION PORTFOLIO

FY2014 Activities and Accomplishments

The Bone and Occupant Protection Portfolio is composed of research projects that increase NASA’s understanding of the risk of bone fracture; spinal nerve compression and back pain; accelerated osteoporosis; and renal stone formation. The Occupant Protection (OP) portion of the portfolio addresses the risk of injury due to dynamic loads.

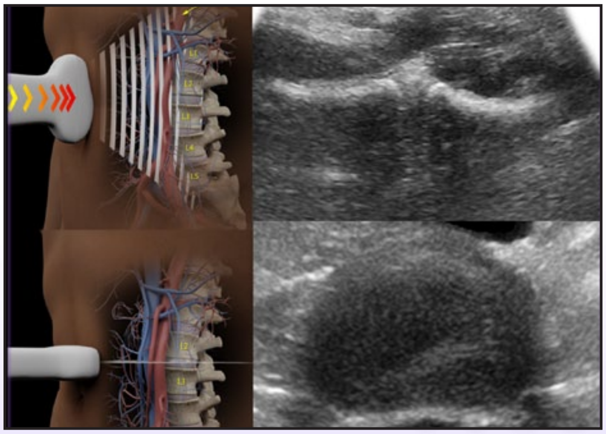
In FY2014, the Bone Summit Research and Clinical Advisory Panel (RCAP), first assembled in 2010, was reconvened for the Bone Summit II. The purpose of the RCAP is to focus efforts to obtain essential measurements to develop clinical practice guidelines or other relevant standards and practices. The RCAP made several recommendations such as refining the strategy for assessing relative fracture risk.

Completion of On-Orbit Sonographic Astronaut Vertebral Examination (SAVE)

Astronauts have a higher incidence of spinal injury than non-astronaut populations, and many report back pain in the early weeks of spaceflight. The Sonographic Astronaut Vertebral Examination (SAVE) study, also known as Spinal Ultrasound led by Dr. Scott Dulchavsky, has examined the spinal structure during flight to understand the mechanisms leading to in-flight back pain and postflight injuries.

Seven crewmembers were examined by magnetic resonance imaging (MRI) and ultrasound before and after flight. Using 'just-in-time' training software and remote guidance, ultrasound assessments were repeated three times during flight. The study demonstrated that this novel approach could be used in other extreme environments without access to MRI.

Initial results indicate that different changes occur in intervertebral disc (IVD) heights and angles in different parts of the spine. The overall height of lumbar IVDs tends to increase throughout flight, but the combined cervical IVD height decreases by flight day 30 and remains decreased through the postflight examination. Changes in disc-to-disc angles indicated an overall straightening of the spine in spaceflight. MRI analysis revealed asymptomatic but radiologically notable deviations in the spine structure or geometry in six subjects before flight, and in all seven subjects after landing.



The SAVE study utilized ultrasound to examine the possible change in spinal structure during spaceflight. The height of lumbar IVDs trends toward increasing throughout flight.

Overall, data indicate that dynamic changes occur in spinal morphology and pathology over the course of a spaceflight mission, and these changes may be linked to postflight injury outcomes. This information will be used to better define the risk of spinal injury and suggest approaches to mitigation strategies.

Summary of ISS Bone Outcome Measures Presented to the Human System Risk Board

The unique nature of the space environment, and its impact on bone strength, requires evaluating both clinical and research data to define a risk for bone fracture during spaceflight and after return to Earth. Consequently, an assessment of bone outcome measures in ISS astronauts was provided to facilitate the understanding and management of fracture risk due to prolonged spaceflight exposure.

The crux of the bone fracture risk in astronauts is centered on measuring the correct bone outcomes which reflect changes in bone strength due to spaceflight, and on determining how these changes influence the probability of fracture. The clinical test used by NASA measures bone mineral density (BMD) using the same test that is applied to at-risk populations, such as postmenopausal women and the elderly.

More than ten years' of astronaut medical data substantiated that declines in BMD are targeted to typically weight-bearing bones, underscoring the localized detriments of mechanical unloading. The data also confirmed that declines in BMD are rapid, suggesting they are effects of aggressive cellular activity that cannot be detected by current imaging technology. However, the preflight BMD for astronauts was high enough that none have returned from a 6-month mission with a BMD more than two standard deviations below the average of a young, healthy population.

HHC

Historically, NASA has utilized Dual-energy X-ray absorptiometry (DXA) to determine bone density. Study findings suggest QCT provides a better assessment of bone outcomes.

However, research studies using quantitative computed tomography (QCT) revealed that the BMD of different compartments of bone—cortical bone versus cancellous or trabecular bone—changes at different rates, both in space and with recovery back on Earth. This finding highlights the insufficiency associated with the sole reliance on BMD to assess fracture risk, particularly for bone loss that is atypical, that is, not related to aging. Therefore, the integration of additional bone outcomes into probabilistic fracture models may change the current estimations of fracture likelihood both for long-term spaceflight and for the lifetime of a population on Earth.

TECHNOLOGY & INFRASTRUCTURE PORTFOLIO

FY2014 Activities and Accomplishments

The Technology and Infrastructure Portfolio supports the development and implementation of countermeasures to protect against the health effects of weightlessness. These projects include the Digital Astronaut Project (DAP) and the Advanced Exercise Concepts (AEC) Project. The DAP develops computational models of physiological systems affected by spaceflight and physiological simulations that help quantify health, safety, and performance risks. The AEC Project establishes requirements for exercise equipment to provide the countermeasures prescribed for astronauts within the constraints imposed by the space vehicle and the astronauts' habitat on the moon or Mars. In 2014, the Artificial Gravity (AG) Project was added to the portfolio to further investigate the feasibility of using AG as a countermeasure.

Digital Astronaut Project Provides Estimation of Exercise Forces to MPCV Designers

The DAP implements computational models to assess spaceflight risks to health and performance and enhance countermeasure development. DAP currently supports the Exercise and Performance Portfolio by integrating biomechanical models of specific exercise movements with dynamic models of the devices on which the exercises were performed. The output of these models are used to generate loading conditions for physiology models that simulate bone and muscle adaptation to exercise.

In support of the Multi-Purpose Crew Vehicle (MPCV) design team, DAP utilized modeling and simulations to calculate the envelope of expected forces between an exercising astronaut and the spacecraft. This information was provided to the team to use in their analyses of loads, dynamics, and guidance navigation control. As part of this work, several models of increasing fidelity were developed.

Although no specific exercise device has been selected for the MPCV, this database of data and simulation models enables designers to obtain an early understanding of possible loads on the vehicle. The database is being used to ascertain the need for, and the design of, vibration isolation systems to limit forces imparted to the ISS for upcoming in-flight testing of these devices.

AEC Downselects to Three Concepts for Exploration-Class Mission Exercise Hardware

As NASA focuses on missions beyond low Earth orbit (LEO), the constraints imposed on in-flight exercise equipment will increase. Proposed vehicle designs have limits to equipment volume, mass, and power consumption that are more stringent than for the ISS. Current ISS exercise hardware will not be suitable for long-duration missions; therefore, AEC is utilizing multiple procurement strategies to develop a compact exercise device such as Innocentive, the Small Business Innovation Research program, NASA@Work, and directed work.

Over the past year, the AEC Project baselined functional requirements to define the exercise device goals for a exploration-class mission and evaluated a number of new exercise technologies in a comprehensive trade study. The Project narrowed the field by selecting three candidate technologies that were subsequently tested in JSC's Exercise Physiology Laboratory with humans in the loop. The tests evaluated their performance against requirements and human factors considerations. All hardware candidates showed promise for providing resistive exercise and some also provided aerobic conditioning. Additional training studies and modifications were recommended before any of the candidates could be considered for a flight demonstration.

International Working Group formed to Study Development Path for Artificial Gravity

The use of artificial gravity (AG) as an integrated countermeasure has intrigued scientists and engineers for decades. Virtually all the identified risks associated with bone loss, cardiovascular deconditioning, muscle weakening, sensorimotor disturbances, space anemia, and compromise of the immune system might be alleviated by appropriate application of AG. However, experience with AG in space has been quite limited and a human centrifuge is currently not available onboard the ISS. A complete research and development program is warranted before the best technique for implementing AG in space can be decided.

In 1999, NASA hosted an AG workshop to explore the utility of AG as a multisystem countermeasure during long-duration, exploration-class spaceflight.

Nearly 100 participants from around the world attended the Artificial Gravity workshop held at Ames Research Center.

In 2014, NASA hosted a second workshop to bring together the international AG community to review the current status of AG facilities and research plans. Attendees discussed the challenges to implementing AG countermeasures in human exploration missions and created an international working group. This group hopes to answer the questions in a timely manner to influence decision making for the next generation of space exploration missions.

Nearly 100 scientists from the U.S. and abroad participated in an update of what we know about AG today. In particular, emphasis was put on integrating engineering aspects with physiological health requirements. It is essential to establish collaboration between engineering and physiological research as early as possible in the evaluation and trade-off processes. Furthermore, including presentations from NASA's international partners was a goal of the workshop to exploit available worldwide resources to lower costs and gain the best knowledge.

The proceedings and recommendations from the workshop were published as a NASA technical memorandum in FY2014. Also in 2014, NASA began laying out a research plan that addresses the tasks needed to identify resources required for a vehicle using intermittent or continuous AG as an integrated countermeasure.

FUTURE PLANS

In FY2015, HHC continues its commitment to the development and assessment of medical standards, vehicle and spacesuit requirements, and countermeasures to ensure crew health during all phases of flight. As Portfolios develop and validate countermeasures, they will be transitioned to operational use. HHC will continue to monitor crew health and performance through a battery of standard measures on all crewmembers. This will allow HRP to evaluate countermeasures that work for one physiological system and ensure another system is not negatively affected.

In the coming year, several VIIP investigations will end and the results from these studies will inform the knowledge gap surrounding the causation of the syndrome. The VIIP Portfolio will also kick off its flagship study, Fluid Shifts, on the 1-Year Mission.

Future AEC work will include developing requirements and exercise design concepts to meet physiological and vehicle requirements of the Orion capsule for the 10- to 14-day Exploration-2 (EM-2) mission. The EM-2 is scheduled as the first manned mission of NASA's Orion Project with plans to launch as early as 2021.

Also in FY2015, solicitations for Artificial Gravity Project research will begin. As HHC evaluates the effectiveness of its currents countermeasures, artificial gravity will be evaluated as an additional option for future exploration vehicles and habitats.

Artificial gravity may be simulated by spinning part of a spacecraft such as the torus ring on the NASA Nautilus X concept.

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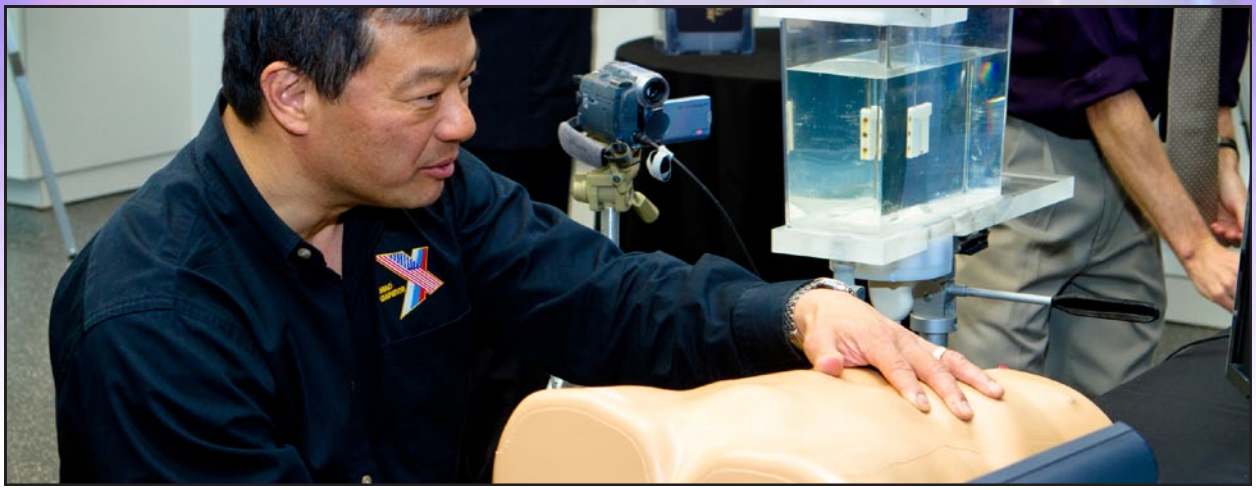
EXPLORATION MEDICAL CAPABILITY ELEMENT



Overview

Human exploration of the Moon, Mars, and other destinations beyond Earth's orbit will present significant new challenges to crew health. During exploration missions, crews will need medical capabilities to diagnose and treat injury or disease. Providing capabilities that overcome these challenges will require new health care systems, procedures, and technologies to ensure the safety and success of exploration missions.

The Exploration Medical Capabilities (ExMC) Element develops medical technologies for in-flight diagnosis and treatment, as well as data systems to maintain and protect patients' private medical data. These data systems also aid in the diagnosis of medical conditions, and act as repositories of information that support relevant NASA life science experiments.

ExMC physicians and scientists develop models to quantify the probability that a medical event will occur during a mission. Personnel also define procedures for treating an ill or injured crewmember without having access to an emergency room and with limited communications with ground-based personnel for consultation and diagnostic assistance. To read more about the ExMC Element, visit http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-exmc.html

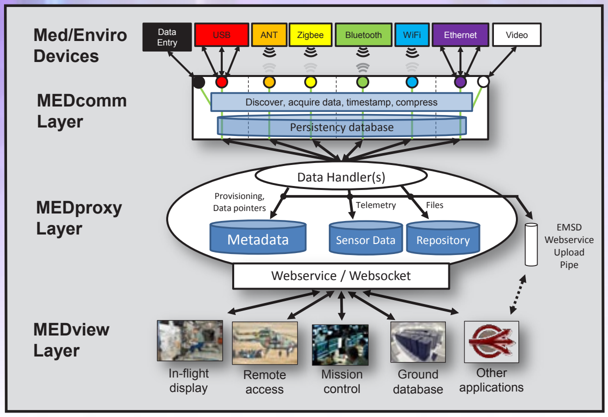
FY2014 Activities and Accomplishments

In FY2014, ExMC continued the development of new medical technologies that improved NASA's ability to respond to medical events on exploration missions. Technology development projects such as consumables tracking hardware, software based ultrasound, advanced procedure development, and integrated medical data management were refined. These projects will utilize the ISS as a test bed to ensure the technologies function in a microgravity environment.

Development also continued on numerous medical databases and models which inform ExMC's understanding of the conditions driving medical risk. Furthermore, the Element engaged in a technology watch program to monitor external technology development efforts to eliminate duplicate activities. Collaborative partnerships were also sought from members of academia, industry, and other areas of government to co-develop medical technologies that could one day be used on exploration class missions.

ISS SpaceMED System to Automate Acquisition of Spaceflight Biomedical Data

Scores of biomedical and environmental monitoring devices have been deployed aboard the ISS which enable the assessment of astronauts' heart rate, blood pressure, and sleep/wake activity. These devices also



Various devices and sensors on the ISS (top row) use different networking protocols making interoperability problematic. The SpaceMED prototype seeks to integrate the data from these devices to facilitate analysis and curation.

monitor environmental parameters such as spacecraft CO_2 and radiation levels. However, these devices are made by different manufacturers and most were never designed to interoperate, synchronize data streams, or coordinate with decision-support or therapeutic devices. As a result, most in-flight data is first sent to ground controllers for time-consuming analysis and curation. This concept of operations will need to change for exploration missions, as communication delays would prohibit timely access to medical and environmental data.

With support from the National Space Biomedical Research Institute, a team led by Dr. Gary Strangman from Massachusetts General Hospital and Harvard Medical School provided a solution which will address this problem. The group developed a prototype platform—called 'SpaceMED' or Spaceflight Medical and Environmental Devices—to seamlessly integrate disparate biomedical and environmental sensors.

The SpaceMED v2.2 software is designed for deployment in all spaceflight settings, from a 2-person rover to a space station or planetary base. The platform operates by continuously "listening" for new devices being turned on or plugged in. It automatically collects, synchronizes, stores, and communicates data without human intervention. All data—both live and archived—can be accessed through a web-based interface by astronauts during flight, or by authorized users in any location with internet access. SpaceMED has proven capable of handling data volumes sufficient for all exploration-class missions.

'First in Man' Clinical Trial to Use Ultrasound to Move Kidney Stones

One in eleven Americans suffer from kidney stones, and astronauts are at an increased risk of forming them because of microgravity, dehydration, and altered bone metabolism associated with spaceflight. A stone can cause debilitating pain as it passes or obstructs urine flow. Obstruction can lead to urinary tract infection, sepsis, renal failure, and even death. There are currently no options for removing kidney stones other than surgery. NSBRI has funded the University of Washington Applied Physics Laboratory to develop a noninvasive, non-ionizing, ultrasound-based technology to reposition stones within the kidney or ureter to facilitate natural clearing. The

NSBRI-funded researchers from the University of Washington's Applied Physics Laboratory (top photo) have developed a novel noninvasive ultrasound technique capable of diagnosing and moving stones of all sizes including large ones (bottom photo).

ExMC

technology can be implemented as a software upgrade on NASA's flexible ultrasound system. With the ultrasound probe positioned against the patient's skin, the operator first visually locates the stone, and then focuses ultrasound waves to that precise location, thereby inducing movement of the stone.

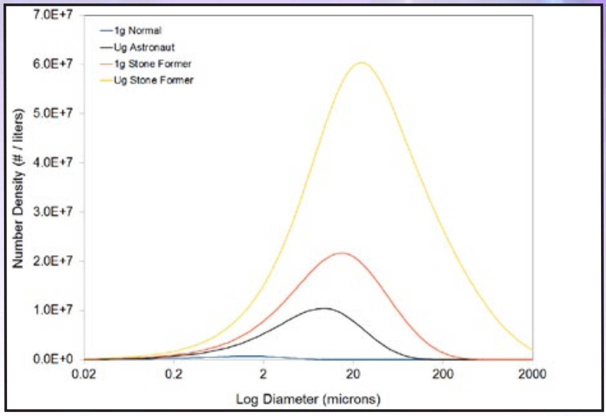
The technology is currently being tested for the first time in humans through an FDA-approved clinical trial. Very large stones were successfully moved, demonstrating the potential to immediately relieve pain and delay the need for emergency surgery. Small stones were expelled from the kidney, and four out of five of the patients treated passed those small stones naturally without requiring additional surgery.

Work is underway to improve the movement and detachment of stones that have adhered tightly to surrounding tissues. In all subjects, the procedure was successful in moving stones with no discomfort or adverse events. A start-up company, Sonomotion, Inc., has been formed to commercialize this transformative technology, not just for space, but also for Earthbound patients.

Integrated Medical Model Completes Four-Year Effort to Develop Renal Stone Model

The Integrated Medical Model (IMM) is a decision-support tool useful to spaceflight mission planners and medical system designers for assessing risks and optimizing medical systems. The IMM uses an evidence-based, probabilistic risk assessment approach within the operational constraints of spaceflight.

In FY2014, the IMM satisfied more than 10 support requests, bringing the project's lifetime total to over 67 support requests for customers in the ISS, Crew Health and Safety, and Commercial Crew Programs. These IMM requests included simulations to assess medical risk levels and requirements for the ISS and commercial crew vehicles, and a prediction of the medical consumables most likely to be needed for exploration missions.



IMM results suggest that 'normal' astronauts (black line) have about the same likelihood of developing kidney stones as 'stone formers' on Earth (red line.)

The IMM also completed a four-year effort to develop a deterministic model of renal stone formation on exploration missions. Due to a lack of clinical data on renal stone formation in microgravity and associated countermeasures, a review panel required a comprehensive model to provide input data to renal stone formation risk analysis.

Data from the model shows that in microgravity, astronauts who are not "stone formers" on Earth have about the same likelihood of producing renal stones as Earth-based stone formers. Additional findings suggest that stones will grow more through agglomeration than crystal surface growth.

ExMC Performs Auscultation Audio Study to Evaluate Use of Electronic Stethoscope

ExMC recognizes the technology gap of limited capability to auscultate, transmit, and record internal body sounds during exploration missions. Several auscultation studies have been conducted in simulated spacecraft noise environments, but no evaluations have included actual spaceflight data. Therefore an evaluation of the Littmann 3200 electronic stethoscope for store-and-forward auscultation was conducted during FY2014 using data collected in a spacecraft environment.

The Littmann 3200 electronic stethoscope was flown by JAXA and evaluated by ExMC. It facilitates the recording of body sounds and features ambient noise reduction technology.

The Japan Aerospace Exploration Agency (JAXA) included a Littmann 3200 as part of their ISS onboard diagnostic kit experiment. Through a data-sharing agreement with JAXA, the ExMC team acquired cardiac recordings made in the ISS JEM module from two crewmembers. In addition, cardiac, lung, and bowel sound recordings were collected in multiple ISS modules by a NASA physician astronaut using the Littmann 3200, made possible through a separate equipment use agreement with JAXA.

Physicians performed blinded ratings of stethoscope recordings, collected from ISS astronauts and ground control subjects, for background noise, clarity, comparability to examining a live patient, and clinical utility. In-flight recordings were randomly presented along with control recordings made in the presence of various levels of simulated spacecraft noise. Control sounds were selected for varied background noise and quality, and were used to create a standard curve to which the in-flight recordings were compared.

Cardiac recordings were in the "acceptable" to "poor" range, with those collected in a more controlled manner scoring better. Three of four lung recordings scored in the "ideal" range, but three bowel recordings of short duration scored substantially below the "acceptable" range. Since other methods such as ultrasound would likely be the diagnostic tools of choice for cardiac and bowel problems, it is significant that lung sounds were deemed clinically useful in this evaluation. With proper training of operators and optimized selection of stethoscope modes and recording techniques, commercial electronic stethoscopes may be sufficient for exploration medical needs.

FUTURE PLANS

Tracking medical consumables represents a significant challenge on the ISS because of the amount of crew time required to properly count and track items. Accurate usage rates for medical consumables are essential to optimize resupply and planning for exploration missions. During FY2015, ExMC will launch to the ISS a Medical Consumable Tracking (MCT) system to determine usage rates for medical consumables. The system uses radio frequency identification technology to tag and identify individual items that, when queried, broadcast a signal to a receiver installed in the Crew Health Care System stowage rack. The MCT system will be installed at least six months and will report inventory on a monthly basis.

Also in FY2015, ExMC will be validating viable strategies to automate the movement of biomedical data without crew and ground controller involvement. The ISS generates a significant amount of biomedical data from a variety of medical and exercise devices which is routinely managed by ground controllers. Exploration missions however, challenge this paradigm and require biomedical data to be largely independent of ground controllers. This project, called the Exploration Medical System Demonstration, will be tested in the Human Exploration Research Analog.

SPACE HUMAN FACTORS AND HABITABILITY ELEMENT

Overview

The Space Human Factors and Habitability (SHFH) Element consists of three main research portfolios: Advanced Environmental Health (AEH), Advanced Food Technology (AFT), and Space Human Factors Engineering (SHFE).

The AEH portfolio focuses on understanding the risk of microbial contamination to crew health and safety, quantifying the virulence changes of microorganisms in response to prolonged microgravity exposure, and establishing permissible limits for exposure to potential toxins such as lunar and celestial dust. AEH also proposes countermeasures that make use of new technology and changes in spaceflight operations, and it makes recommendations for future requirements to protect environmental quality, food, and crew health and performance.

The AFT portfolio focuses on reducing the mass, volume, and waste of the entire integrated food system to be used during exploration missions, while investigating methods to extend the shelf life and acceptability of food items to five years. AFT also researches bioregenerative solutions as a component of the overall food system, and investigates not only food quality and nutrition, but also the technologies for food preparation and storage.

The SHFE portfolio establishes human factors standards and guidelines that govern the interaction of the human system with hardware, software, procedures, and the spacecraft environment. The places where a human interacts with another system is called an "interface." SHFE provides improved design concepts for advanced crew interfaces and habitability systems, methods for measuring performance of humans and human-system combinations (including robotics and automation), and validated human models for determining and predicting the effects of interface designs on human performance. SHFE also facilitates development of tools, metrics, and methodologies for use in implementing, assessing, and validating standards and requirements.

To learn more about SHFH, please visit http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-shfh.html

FY2014 Activities and Accomplishments

The SHFH Element completed a major strategic planning effort to determine the critical research path and priorities for each risk to crew health and safety that is associated with SHFH. The strategic planning effort included identifying experiments to be performed either in ground-based analog environments or on the ISS, and soliciting new research efforts required to close the knowledge gaps. Collaborative efforts were initiated with other Elements such as Behavioral Health and Performance (BHP) and Human Health and Countermeasures. SHFH participated in the Department of Defense (DoD) Human Factors Engineering Technical Advisory Group meeting as well as the 6th International Congress of Medicine in Space and Extreme Environments to establish potential collaborations with the DoD and international partners.

ADVANCED ENVIRONMENTAL HEALTH PORTFOLIO

FY2014 Activities and Accomplishments

AEH encompasses the risk of adverse health effects due to alterations in host-microorganism interactions as well as the risk of adverse health effects of exposure to dust and volatile compounds encountered during space exploration. This year saw a number of key accomplishments in the field of lunar dust research, culminating in a final permissible exposure limit (PEL) standard for chronic exposure set at 0.5 mg/m^3.

The MicroHost team delivered their report with detailed findings and recommendations from three expert panels. The panels reviewed the current microbiological spaceflight requirements for potable water, spaceflight foods, and vehicle air and surfaces.

Additionally, researchers conducting a solicited study designed to gather novel information on changes to the crew microbiome during spaceflight began collecting data during flight on the ISS. Flight data collection and sample return for the first two flight subjects is complete, and analysis of these samples is currently underway.

Additionally, a new one-year task was awarded as part of the NASA Research Announcement (NRA), and it is expected to provide key insights into which species of microorganisms may acquire altered virulence characteristics during spaceflight.

The knowledge gaps under the MicroHost Risk were redesigned to organize the specific research efforts required for risk characterization. The changes include hazard identification and characterization, dose-response and exposure assessment, as well as investigation into countermeasures. These changes in the knowledge gaps will also foster better communication of the intent and path to closure within the MicroHost Risk.

ADVANCED FOOD TECHNOLOGY PORTFOLIO

FY2014 Activities and Accomplishments

AFT mitigates the risk of performance decrement and crew illness due to an inadequate food system, through the investigation of methods and technologies that enhance the safety, nutritional content, acceptability, and shelf life of the space food system, in order to provide space crews with adequate nutrition for all of NASA's current design reference missions.

This year, a new collaboration with the Kennedy Space Center Space Biology team began an investigation regarding a sustainable pick-and-eat salad crop system to supplement the prepackaged food system. AFT researchers also completed a new task in collaboration with AEH this year to determine a delivery method for probiotics in space, where refrigerators and freezers are not available for food storage and food must be shelf-stable for two to five years.

Results indicate that probiotics should be stored under refrigerated or frozen conditions to retain stable viability and consistent delivery of adequate dose, especially as mission length increases. Additionally, data indicate that delivery in a rehydratable dairy or similar food matrix is better than a capsule to deliver stable and consistent amounts of probiotics through gastrointestinal transit.

Food Processing Studies Seek Higher Quality Space Food for Long-Duration Missions

The current processing of food for space stabilizes the items so that microbiological spoilage does not occur

An AFT researcher prepares Sweet and Sour Pork for microwave-assisted thermal sterilization at Washington State University. Because packaging was inadequate, the resulting product did not have a longer shelf life than the current product.

even when the foods are stored for extended periods at ambient temperatures. Unfortunately, this processing also leads to degradation of nutrients and changes in quality that become more pronounced as the foods age. An inadequate food system is one of the critical risks for long-duration human space missions.

AFT researchers, led by Dr. Maya Cooper of Lockheed Martin, have examined two emergent food-processing technologies to identify a pathway to stable, wet-pack foods without the detrimental effects. Both microwave-assisted thermal sterilization (MATS) and pressure-assisted thermal sterilization (PATS) were evaluated against traditional processing to determine whether lower heat inputs during processing would produce a product with higher micronutrient quality and longer shelf life. MATS products had brighter color and better texture initially, but these advantages were not sustained. The non-metallized packaging film used in the process likely provided an inadequate barrier to oxygen. No difference in vitamin stability was evident between MATS and traditionally processed foods.

AFT researchers, seeking to optimize freeze-dried food, also examined five processing factors for their potential impact on the quality of freeze-dried food, including the integrity of the food's microstructure. In tests on freeze-dried corn, the initial freezing rate and primary freeze-drying temperature and pressure were linked to final product characteristics.

Neither of the two emergent processing technologies nor the freeze-dry optimization resulted in compelling quality differences from current space food provisions such that a five-year shelf life would be likely with these processing changes alone. However, the improvements achieved in quality of the space food indicated that using a 'hurdle technology approach,' such as pairing processing optimization with a packaging or storage condition improvement, has promise to achieve longer food shelf life.

KSC Evaluates Leafy Green Vegetables for a Pick-and-Eat Diet Supplement on ISS

Long-duration missions have strict limitations regarding food and mass; therefore, researchers are evaluating different methods for growing 'pick and eat' crops to supplement a packaged food menu. In FY2014, the ISS Program installed the Veg-01 experiment, nicknamed "Veggie", a plant growth chamber utilizing a unique system of growth media pillows. KSC researchers are evaluating several varieties of leafy vegetables with the goal of selecting those with the best growth, nutrition, and taste acceptability for ISS.

Candidate crops were selected based on published nutritional values coupled with a subjective desirability factor. Plants were grown under conditions similar to the Veggie plant growth chamber on ISS. Eight varieties of leafy greens were grown: 'Tyee' spinach , 'Flamingo' spinach, 'Outredgeous' Red Romaine lettuce , 'Waldmann's Dark Green' leaf lettuce, 'Bull's Blood' beet, 'Rhubarb' Swiss chard, 'Tokyo Bekana' Chinese cabbage, and Mizuna.

Chinese cabbage produced the largest plants in the shortest period of time and the highest calcium content. Chinese cabbage also had the lowest iron levels, a condition more desirable for the space diet. Analysis

A recent KSC study evaluated leafy vegetables for possible use on the ISS as a 'pick-and-eat' food. Chinese cabbage and beets had favorible results on growth rates and nutritional analysis.

indicated that Outredgeous lettuce had the highest potassium levels and beets also had the highest iron and magnesium levels.

For sensory evaluation, crops were sent to the JSC Space Food Systems Laboratory. Tasters evaluated overall acceptability, appearance, color intensity, bitterness, flavor, texture, crispness and tenderness. All varieties received acceptable scores with overall ratings greater than 6 on a 9-point hedonic scale—the most widely used scale for measuring food acceptability. Chinese cabbage was the highest rated, followed by Mizuna, 'Outredgeous' lettuce, and Swiss chard.

SPACE HUMAN FACTORS ENGINEERING PORTFOLIO

FY2014 Activities and Accomplishments

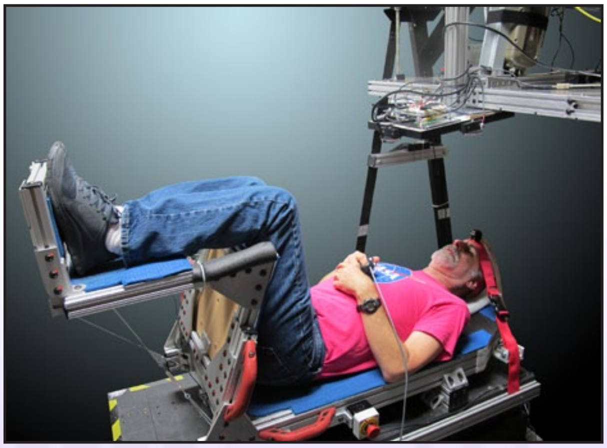
This year SHFE achieved a number of key accomplishments. Strategic replanning of each of the five risk areas resulted in a more refined Path to Risk Reduction (PRR). Three tasks in the habitability, human-computer interaction (HCI), and training risk areas were selected to participate in ISS increments including the one-year mission. This research will provide insight into some of the human-factors effects of extended mission durations.

Two tasks, awarded as part of the Human Exploration Research Opportunities NRA, support the habitability risk to provide guidelines for tools and methods for data collection, modeling, and analysis for design and assessment of vehicles and habitats. An Omnibus NRA was awarded to support research contributing to guidelines for mitigating the HCI risk of performance decrements due to the spaceflight environment. The Human Performance Data Project, led by Dr. Jurine Adolf from Lockheed Martin, was initiated, and focuses on defining, identifying, storing, and making data associated with human performance in human spaceflight available for use.

Additionally, research was completed on two fundamental teleoperations issues: communication delays and remote camera rotational misalignments. A new quantitative model was developed to predict performance degradations caused by comm delays and camera control issues. This model will provide a basis for predicting outcomes and weighing the impacts.

Research Leads to New Requirements for Maximum Allowable Lateral Vibration

Analyses of the Space Launch System (SLS) indicated that thrust oscillation in the system's solid rocket boosters during launch could cause crewmembers to experience side-to-side vibrations in the frequency of 12 Hz. This raised concern for the ability of astronauts to carry out critical vision-dependent tasks.



A vibration chair test subject with a head restraint strap performs a number-reading task.

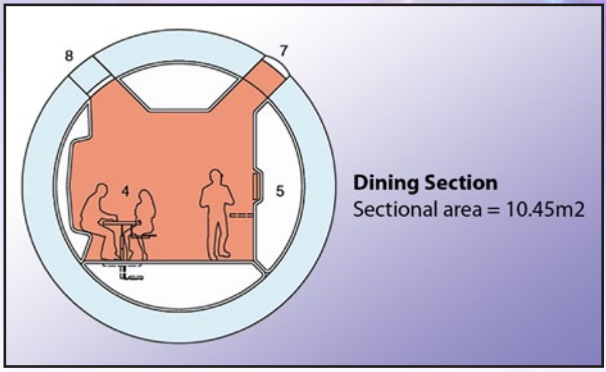
Because of the lack of relevant spaceflight experience or ground-based data, HRP funded an investigation that supported the development of requirements for lateral vibration based on visual performance.

The study, conducted at Ames Research Center by Dr. Bernard Adelstein, used a stationary display with a vibrating seat. The subjects performed the same number-reading task used in 2008 to study the visual impact of 12 Hz vibration in the chest-to-spine direction. Those findings suggested the chest-to-spine vibration caused reading decrements below an amplitude of ±0.5 g. In contrast, the new findings for side-to-side vibration suggest that task error rates and response times were unaffected up to the maximum ±0.7 g amplitude tested. This level exceeds the current worst-case predictions for SLS thrust oscillation vibration. These new results led the SLS and Orion programs to establish 0.7 g as the maximum allowable amplitude for lateral vibration frequency content in the 10- to 13-Hz band.

Net Habitable Volume Workshop

SHFH partnered with BHP in hosting a panel of subject matter experts (SMEs) in a Net Habitable Volume (NHV) Consensus Session. The session, which took place in January 2014, helped characterize and quantify NHV needs for long-duration spaceflight. A group of five panelists was charged with deriving a minimum acceptable NHV for a given Mars mission. Tasks included defining the dependencies of the number according to caveats and countermeasure scenarios, and determining how the minimum acceptable NHV would change relative to duration.

Before the session began, NASA provided the panelists with background information including specific exploration-mission parameters such as duration, crew size, crew composition, communication delays, and level of crew autonomy. During the session, the panel created a hypothetical vehicle layout which accommodated a set of critical functions affecting the minimum acceptable NHV.



A dining area concept used in the layout to derive a minimum acceptable net habitable volume of 25 m^3 per person.

Based on the characteristics and parameters of the exploration-class mission defined in Mars Design Reference Mission (DRM) 5.0, the SMEs, with concurrence of the NASA representatives, recommended a minimum acceptable net habitable volume of 25 cubic meters per person. This number resulted from defining the volume required for different functional areas and zones, and making use of overlaps to minimize the total volume. A report summarizing the results of the consensus session will be available as a NASA Technical Memorandum in FY2015.

SHFH FUTURE PLANS

SHFH will continue its efforts to establish strong synergies with the other Elements, and with external organizations as well as international partners. This will allow SHFH to identify and make use of research in progress by other organizations, and possibly influence these organizations' research plans to promote mutual benefit from the outcomes. In addition, SHFH will increase its interaction with the NASA program offices and technology development projects to ensure smooth and effective implementation of research findings. Major milestones planned for delivery in FY15 include integrated food processing, packaging and storage concepts for total food system improvements and identification of technology challenges to reaching a five-year shelf life, as well as providing initial NHV guidelines and methodology.

BEHAVIORAL HEALTH AND PERFORMANCE ELEMENT

Overview

The Behavioral Health and Performance (BHP) Element conducts and supports research to reduce the risk of behavioral and psychiatric conditions. These include performance decrements due to inadequate cooperation and communication within a team and the risk of errors due to fatigue resulting from sleep loss or work overload.

Long-duration missions, beyond low Earth orbit, will require crews to adapt to increasingly autonomous operations in isolated, confined, and extreme environments. Crews are faced with other challenges such as long periods of heavy workload, separation from home, and altered day-night/light cycles. Microgravity, carbon dioxide, and radiation are other factors that may lead to adverse behavioral and performance outcomes.

BHP's strategy for addressing its risk-reduction research is derived in a systematic manner and driven by operations. Spaceflight analogs and other research environments are carefully assessed to ensure that the individual, team, environment, and mission characteristics fit the research question at hand. To address these concerns, BHP categorizes research into three Portfolios: Behavioral Medicine, Team, and Sleep/Fatigue.

The Behavioral Medicine Risk Portfolio works to develop self-assessment tools that use unobtrusive and objective measures of mood, cognitive function, and other behavioral reactions. The Team Portfolio examines team performance, including crew cohesion and communication, to develop tools and technologies that monitor and support teams throughout autonomous operations. The Sleep/Fatigue Portfolio focuses on countermeasure development, including lighting protocols, medication recommendations, and tools that optimize work-rest schedules.

To read more about the Behavioral Health and Performance Element, please visit http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-bhp.html.

SLEEP/FATIGUE PORTFOLIO

FY2014 Activities and Accomplishments

The Sleep/Fatigue Portfolio addresses the risk of performance errors due to fatigue resulting from sleep loss, circadian desynchronization, and extended wakefulness and work overload. While progress has been made, knowledge gaps remain. In FY2014, a BHP publication revealed that sleep remains reduced in spaceflight despite the use of countermeasures. It showed the average nightly sleep duration for both Shuttle and ISS astronauts was around 6 hours and for about 20% of nights, circadian rhythms were misaligned. Subsequent efforts in the Sleep/Fatigue Portfolio seek to further characterize sleep and circadian rhythms during flight, and focus on the validation and refinement of countermeasures such as lighting protocols, medications, and sleep-wake models.

Countermeasures Developed to Address Published Findings on Sleep Deficiencies

In the September 2014 issue of *The Lancet Neurology*, an article by BHP researchers Drs. Charles Czeisler and Laura Barger of Harvard Medical School/Brigham and Women's Hospital, revealed that astronauts spend less time sleeping during flight than before or after flight, despite using sleep medications regularly. This investigation was the most extensive study of sleep during short- and long-duration missions. In many studies of human rest-activity or sleep-wake cycles, subjects wear an activity monitor or "actigraph" on their wrist that records physical activity. Analysis of sleep-wake data collected from 21 ISS crewmembers and 64 Shuttle astronauts indicated that astronauts obtained an average nightly sleep duration of around six hours. Furthermore, findings suggest that astronauts faced significant chronic sleep debt, even three months before launch, and that sleep decrements occurred even with the regular use of sleep medications.

Fortunately, NASA has been working for the past several years to develop evidence-based countermeasures to fatigue and provide them to both flight and ground crews. For example, a collaborative effort with flight surgeons and BHP personnel yielded clinical guidelines for the assessment of sleep and circadian difficulties. This work resulted in the implementation of anti-fatigue countermeasures—particularly for those working overnight shifts and crossing time zones before spaceflight. Crew surgeons now have a standardized method for treatment such as providing individualized medication and lighting recommendations, as well as stress management training led by BHP psychiatrists.

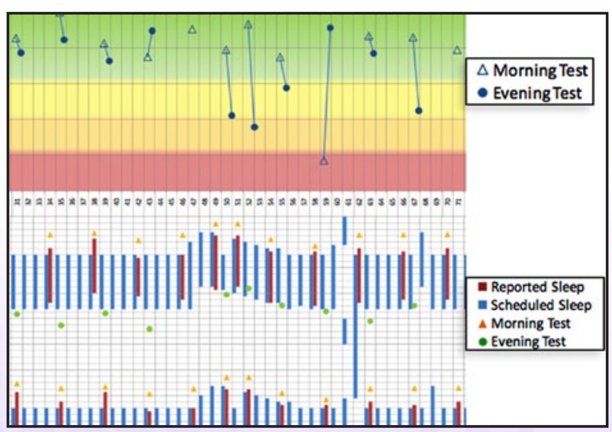
An article published in September 2014 details the sleep decrements suffered by short- and long-duration spaceflight crew. Photo Credit: The Lancet Neurology, an Elsevier journal

BHP

Completion of Flight Study Examines Effect of Fatigue and Other Factors on Performance

The Reaction Self Test (RST) provides astronauts with objective feedback on neurobehavioral changes in vigilant attention, psychomotor speed, state stability, and impulsivity. It also records subjective ratings of workload, sleep quality, tiredness, fatigue, physical exhaustion, and stress. Since the test is brief and takes only 3-5 minutes, it is well suited for repeated use.

The RST Study, led by Dr. David Dinges, from the University of Pennsylvania, seeks to determine the extent to which test performance of astronauts is affected by fatigue, sleep quality, sleep duration, and abrupt changes in shifts during ISS missions; to perceived workload and tiredness; to physical exhaustion and stress; and to overall time in mission. It also seeks to evaluate the usefulness of performance feedback.



An example of in-flight testing performance ranging from green, for good performance, to red, for poor performance.

Acquisition of data began with Expedition 21/22 in September 2009 and targeted 24 astronauts. Data collection was completed in FY2014 and baseline, in-flight, and postflight assessments totalled 2,964 tests. All data was verified by quality control, and 100 variables were extracted from each completed test without any loss of data during ISS download.

During debriefs, astronauts were shown graphic summaries of their data to facilitate recall and interpretation of specific activities and events relative to their performance. BHP researchers are analyzing the data and a final report will be available in June 2015.

BEHAVIORAL MEDICINE PORTFOLIO

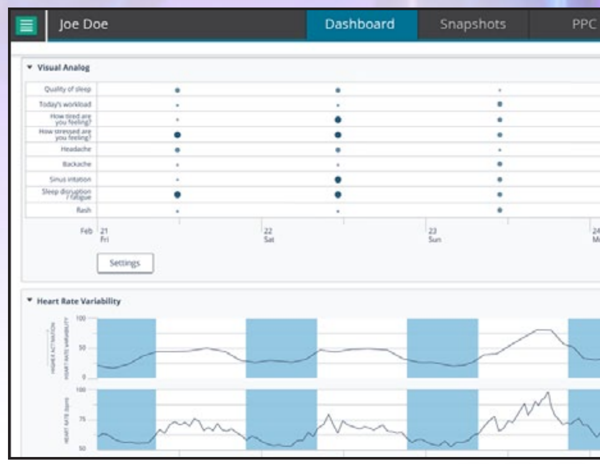
FY2014 Activities and Accomplishments

The Behavioral Medicine Portfolio addresses the risk of adverse behavioral conditions and psychiatric disorders during spaceflight. This year, BHP began funding new work to focus on biomarkers which may help predict behavioral health outcomes. Additionally, the use of the Human Exploration Research Analog (HERA) facility provided a new environment to test behavioral health and performance in isolated and confined environments.

Earlier this year, testing for development and validation of a new, brief cognitive test battery was completed with mission controllers at JSC. In September, the software arrived at the ISS to begin spaceflight testing. Also, results from the 520-day isolation chamber study conducted by the Russian Institute for Biomedical Problems were published, and provided new insight into psychological symptoms exhibited in an isolated environment.

New Software Integrates Stress Data and Vehicle Events into One 'Dashboard'

BHP scientists working with Pulsar Informatics delivered the Individualized Stress Detection System module for the Behavioral Health and Performance



New BHP software integrates crew stressors with heart rate variability and vehicle events to give flight surgeons insight into a crewmember's well-being.

Dashboard (BHP-DS). The BHP-DS provides a user interface to track astronaut behavioral health indicators in the context of the mission timeline of activities such as vehicle dockings and EVAs, and environmental hazards such as increased noise levels and CO_2 exposure. This data is unobtrusively collected from multiple sources and integrated. The dashboard provides behavioral health feedback and aids in the selection of countermeasures. The new module is designed to facilitate the collection, analysis, and display of measures related to hyperarousal and sleep disruption.

Hyperarousal and chronic insomnia are associated with increased activation of the sympathetic nervous system. Individuals who suffer from insomnia have higher heart rates while awake and asleep, as compared to healthy subjects. They also have an exaggerated heart rate response throughout a stressor event. Heart rate variability (HRV) provides information about the ability to adapt to physiological changes. Low HRV indicates an increased susceptibility to stress and is associated with insomnia and other medical conditions including depression, anxiety disorders, panic disorders, and post-traumatic stress disorder.

Pulsar developed mathematical and statistical algorithms to detect when variables associated with chronic stress, hyperarousal, and sleep disruption exceed preset thresholds. The Individualized Stress

Detection System is intended to support NASA flight psychiatrists, psychologists and flight surgeons. These clinicians can view both individual data or data relative to the crew as a whole to determine whether signs related to chronic stress are elevated for an individual or systematically across multiple crewmembers.

TEAM RISK PORTFOLIO

FY2014 Activities and Accomplishments

The BHP Team Risk Portfolio addresses the risk of performance decrements due to inadequate cooperation, coordination, communication, and psychosocial adaptation within a team. In FY2014, a BHP study resulted in the use of a new team debriefing technique for flight controller training, which produced significant reductions in the amount of training time required. BHP is working to implement this debrief approach in other areas.

Additionally, BHP identified critical areas of research not yet addressed and defined what—according to the existing literature—is known and unknown in these areas and are applicable to future missions. Critical research needs are now defined and include team cognition, composition, culture, and motivation.

Impact of Communication Delays on Individual and Team Performance

In FY2014, BHP researchers lead by Dr. Lawrence Palinkas of the University of Southern California, studied the impact of a communication delay between the ISS crew and mission control. The study focused on individual and team performance, well-being, and related perceptions of autonomy. Building on results of previous studies with NEEMO crews, this study examined task performance and interactions between the crew and ground with and without delays in communications. The tasks performed varied along dimensions of novelty and criticality.

During Increment 39/40, three astronaut participants performed ten tasks, six under conditions of no delay in communications, and four under conditions of a 50-second one-way delay. After completion of each task, participants answered questions about communication, autonomy, morale, perception of team performance, and the amount of support received.

A study simulated a 50-second one way communication delay with ground controllers to investigate methods to mitigate risks associated with delays inherent in exploration-class missions.

Preliminary analysis of data suggests that examining the impact of communication delays is feasible under certain logistical and operational constraints. Additionally, more preflight training is required to perform highly complex tasks in an autonomous fashion. Participants also independently developed techniques over time for asking and answering questions in more complete fashion. Results are expected to show to what extent individual and team performance levels are influenced by communication delays and what countermeasures help mitigate the associated risks.

HERA Studies Provide Significant Behavioral Research Data; Ideal Platform for Testing

During FY2014, 16 subjects participated in HERA BHP studies for a total of 28 days in the habitat. These studies yielded more than 4,000 hours of video and 2,000 hours of audio recordings of interactions between the crew and mission support staff.

This year's studies included: team cohesion fluctuations; unobtrusive monitoring tools; testing of team

HERA study participants perform a complex task while investigators test unobtrusive cameras to detect indicators of stress.

debriefing strategies; validation of a new cognitive performance evaluation tool; and testing of the effects of communication delay on team performance. For example, a study led by Dr. Steve Kozlowski from Michigan State University focused on testing a new sociometric badge technology for unobtrusively monitoring team cohesion over time. An NSBRI-funded study, led by Dr. David Dinges of the University of Pennsylvania, used HERA as a testing platform for a method of unobtrusively monitoring fatigue and stress through analysis of video data.

HERA has proven to be an invaluable new analog environment for behavioral research producing a density of data rarely seen in spaceflight analogs. The data has informed investigators about the performance of these tools in an operational environment.

BHP FUTURE PLANS

Future BHP One-Year ISS Studies

Current ISS operations make use of proven behavioral health countermeasures; however, during a one-year mission astronauts would remain susceptible to prolonged sleep loss, circadian desynchrony, increased workload and fatigue, as well as changes in behavioral health and cognitive functioning. In FY2015, BHP is sponsoring five research studies during a groundbreaking one-year ISS mission from April 2015 to April 2016. Data obtained from these studies will provide key insights into behavioral health over longer durations than have been studied before.

Future research will characterize the long-term effects of radiation exposure on cognitive function and the likely mechanisms of damage to the CNS. This study will use rodents trained to perform a version of the human Psychomotor Vigilance Test. These rodents will be irradiated with different ion types at doses encountered in the space radiation environment. Extensive post-exposure testing will study relationships between their behavior and the irradiation of specific areas of the brain. A long-term research goal is to develop potential countermeasures for mitigating cognitive impairments induced by space radiation and to test their effectiveness.

Also in FY2015, a prototype of a stress monitoring "wearable" tool will be delivered. The system uses two separate devices that may work independently or together. The first device is worn on the head and the second, which is more unobtrusive, is worn on the wrist. Crewmembers will be able to operate the devices autonomously while also allowing the ground-based clinicians to monitor their behavioral health status. The system will provide meaningful feedback to the crew during exploration missions.

A future study will leverage multiple wearable devices to monitor crewmember stress.

Overview

The Human Research Program supported a number of education and communication initiatives in FY2014 across multiple NASA centers and the National Space Biomedical Research Institute (NSBRI). Additionally, HRP Elements helped support education initiatives including research internships, post-doctoral programs, and summer institutes for interns. Within HRP, the Human Research Engagement and Communications (HREC) Project is committed to engaging and informing the general public about NASA's human health and performance research and technology development.

Mission X Continues International Effort to Address Exercise and Childhood Obesity

In FY2014, Mission X 14 (MX14) completed the first phase of a multi-year international fitness campaign that spanned MX12-MX14. Mission X: Train Like an Astronaut is an international educational challenge focusing on fitness and nutrition, and encourages students to "train like an astronaut." The World Health Organization has designated childhood obesity as one of the most serious public health challenges of the 21st century—and nutrition, physical activity, and the promotion of a healthy lifestyle are the best answers to this largely preventable problem.

NASA, with MX14, spanned the globe with 11 partner space agencies, nearly 24,000 participants, over 600 teams in 24 countries, almost 1,400 adults, and 54 international partner institutions. A fitting conclusion for Phase I was that the combined participation of MX12 through MX14 included more than 53,000 participants who learned about the importance of being physically fit and living a healthy lifestyle.

In FY2014, Train Like an Astronaut (TLA) and Mission X (MX) materials were adapted and made available for people with unique needs. Additionally, TLA and MX worked with astronaut Mike Hopkins to kick off MX14 with a group of Society of Health and Physical Educators (SHAPE) America Teachers of the Year. Using Facebook, kids from around the world followed Mike throughout his six months on the ISS. HREC was excited to have 30 astronauts support these efforts and share their experiences to encourage kids to "Train Like Astronauts."

As MX15 approaches, the project is working to establish a new partnership with the State University of New York at Buffalo's Department of Epidemiology and Environmental Health to expand the project's expertise in pediatric obesity. This partnership seeks innovative ways for children to increase their daily physical activity, improve their understanding of good nutrition, and become excited about human space exploration.

The Mission X 2014 Working Group is comprised of international leaders, teachers, and instructional designers from multiple space agencies and institutions around the world.

New HREC Effort Promotes Research Goals

HREC's Research to Outreach (RTO) project enhances public knowledge and understanding of HRP's work through feature stories and videos. To enrich the story lines, RTO personnel collaborate with the ISS Program Science Office, the JSC External Relations Office, the NSBRI, facilities such as the NASA Space Radiation Laboratory, and principal investigators conducting HRP work.

Each story is submitted to press release services and videos are posted to the NASA YouTube channel. Stories produced in FY2014 garnered interest from high-profile media channels including the *Los Angeles Times*, *The Washington Post*, and the *Discovery Channel*. Website metrics indicate that the popularity of each story is tied to both the subject matter and the timing of the story's release. Some articles received more than 8,000 page views.

The Research-to-Outreach (RTO) project utilizes video interviews of researchers and engineers to educate the public on HRP's latest investigations.

NSBRI Fellowship Program Prepares Graduate Students for Careers in Biomedicine

NSBRI's Mentored Research Fellowship Program in Space Life Sciences at Texas A&M University and the Ph.D. Training Program in Bioastronautics at Massachusetts Institute of Technology (MIT) prepare the next generation of young scientists for careers in high-tech fields. The mentored research program provides funding for curriculum development, including new courses and seminars, and a fellowship program for exceptional graduate students.

To date, 13 fellows have earned doctoral degrees, with many immediately transitioning to careers in industry, academia, or government. Since the program began, students have generated 98 peer-reviewed articles, 1 book chapter, 212 invited abstracts and presentations, and 6 invention disclosures.

Five Candidates Selected for NSBRI First Award Fellowship

Future space life scientists, engineers, and healthcare providers train as independent investigators with support from NSBRI's First Award Fellowship Program at universities across the nation. Fellowships enable young scientists to manage their own space-related biomedical research projects while continuing to learn from experienced faculty mentors. Participants join one of NSBRI's research teams and receive an introduction to NASA Johnson Space Center's research facilities and programs. Since 2004, 39 two-year fellowships have been awarded. To date, First Award Fellows have produced 351 peer-reviewed articles, 12 book chapters, 731 invited abstracts or presentations, and 7 invention disclosures. NSBRI released RFA-14-02, soliciting proposals for the First Award Fellowship Program, in February 2014. Thirty-four proposals

The NSBRI First Award Fellowship program enables young scientists to manage their own space-related biomedical research projects while continuing to learn from mentors.

were submitted and five highly qualified candidates were selected.

NSBRI Summer Apprenticeship Program Offers 10-Week Immersive Experience

Since 1998, 214 undergraduates and graduates have participated in the Summer Apprenticeship Program at NASA Johnson Space Center, Glenn Research Center, or Ames Research Center. This 10-week immersive research opportunity selectively pairs students with a seasoned mentor aligned with their scientific interests. In 2014, NSBRI received 170 applications from students nationwide for the Summer Apprenticeship Program. Applicants represented 93 institutions of higher education in 34 states. Twenty outstanding students were selected. About 73% of Summer Apprenticeship Program alumni have gone on to pursue an advanced degree in science, technology, engineering and math (STEM) related fields.

11TH Annual NASA Space Radiation Summer School Encourages Future Researchers

The 11th annual NASA Space Radiation Summer School was held at the NASA Space Radiation Laboratory (NSRL), located at the Brookhaven National Laboratory in Upton, NY, June 2-20, 2014. The Summer School, sponsored by the Space Radiation Element, is designed to provide a pipeline of young

The 11th Annual Space Radiation Summer School participants stand outside the NSRL at Brookhaven on Long Island.

radiobiology researchers to tackle the challenges of harmful radiation exposure to humans on space exploration missions.

This year, 16 U.S. and international graduate students and postdoctoral fellows participated in the 3-week course. The Summer School was led by a research physicist from NASA Langley Research Center and was taught by leading university and national lab biologists and physicists engaged in space radiation research. It consisted of daily lectures on relevant topics in radiation physics, chemistry, and biology, emphasizing space radiation protection as well as experimental methods in radiation research. In addition to the lectures, the students gained hands-on experience by designing and conducting cell experiments using the NSRL beam facility.

Summer Research Program at Morehouse

The Summer Research Program (SRP) at Morehouse School of Medicine provides laboratory research internships and supplemental learning experiences, such as journal clubs and seminars, to further the preparation of students from population groups traditionally underrepresented in STEM fields. It also encourages students to pursue STEM-related higher education and careers. Since 1997, the SRP has enrolled 78 students through NSBRI sponsorship. Twelve of these students have participated in the Harvard Medical School sleep research program.

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BEHAVIORAL HEALTH AND PERFORMANCE

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