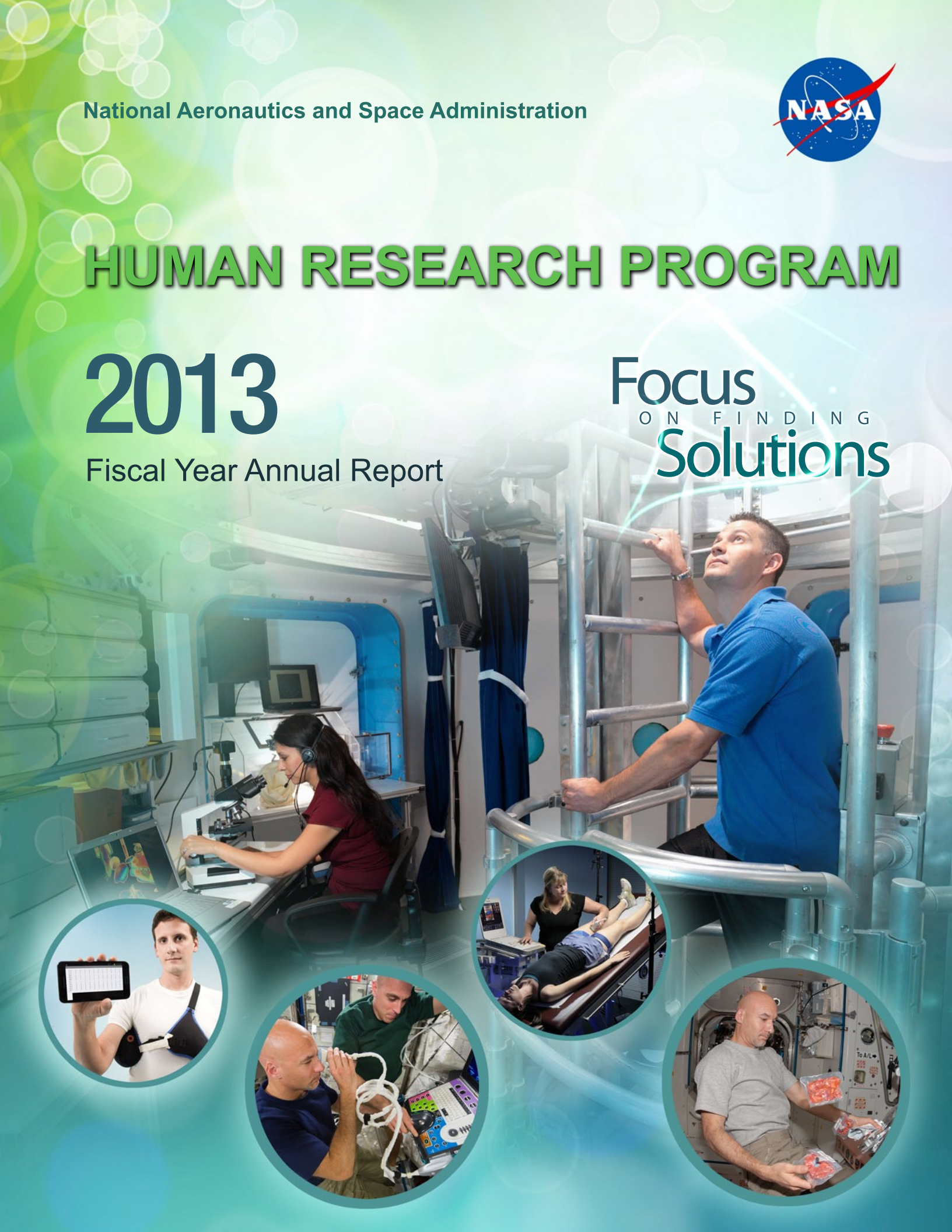
National Aeronautics and Space Administration

HUMAN RESEARCH PROGRAM

2013

Fiscal Year Annual Report

Focus ON FINDING Solutions



Message from the Program Manager

Returning to NASA after five years in academia allowed me to see first hand the incredible progress the Human Research Program has made. The management skills of our program and element teams have created a well-oiled operational research machine that is recognized throughout the agency. We have a sound, well-vetted plan for mitigating the highest-level human system risks to exploration beyond low Earth orbit. And, we are well on our way to realizing the objectives of that plan. All in all, the Program is in excellent shape.

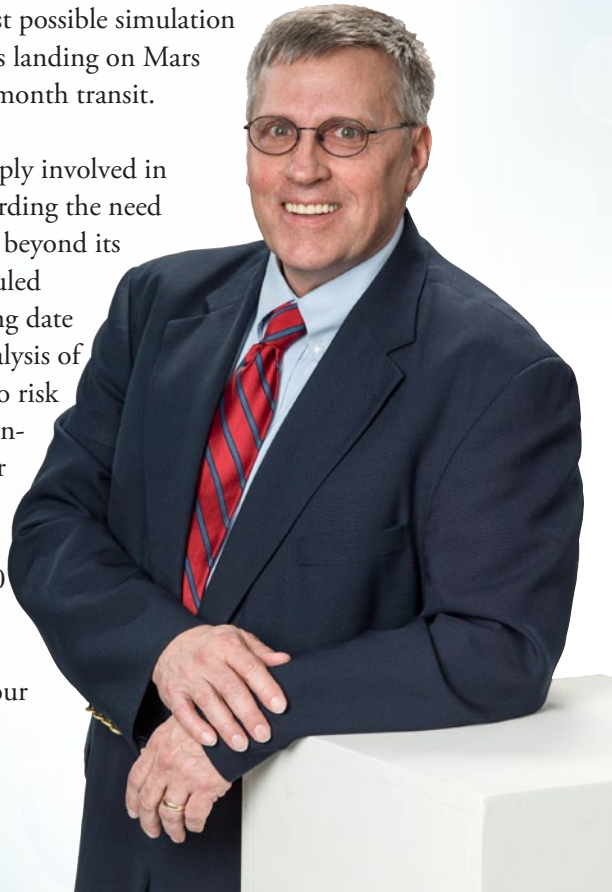
This year saw a number of key personnel changes. My predecessor, Dr. Mike Barratt, returned to the Astronaut Office after selecting me as the fourth HRP Program Manager. Dr. John Charles left his position as HRP Chief Scientist to establish an International Science Office (ISO), and Dr. Mark Shelhamer was appointed as his successor for a two-year term. Also, Dr. Francis Cucinotta, our Space Radiation Element Scientist, retired from NASA after leading research efforts in the biomedical effects of space radiation for 18 years. A competitive process to identify his successor will begin during the first quarter of fiscal year 2014.

A number of bold new initiatives have emerged from our new International Science Office. Dr. Charles became co-chair of the newly commissioned Multilateral Human Research Panel for Exploration (MHRPE), which, among other things, is preparing to manage a one-year mission aboard the International Space Station (ISS). Beginning in 2015, this pilot mission involves two crewmembers–one American and one Russian. A series of joint Russian-American experiments will be implemented to gain insight into the effects of extending mission duration and to help determine whether future one-year missions are warranted to aid in mitigating the exploration risks in our portfolio.

The US crewmember selected for this mission offers a unique research opportunity as he has an identical twin brother who is a retired astronaut. To that end, HRP recently solicited proposals to examine the effects of spaceflight on fundamental biological processes in these two siblings. We anticipate that this will be a first step in introducing systems biology tools and investigators into HRP, and we expect it to lead to closer connections with the GeneLab Project currently being defined at NASA Headquarters.

Another exciting activity to emerge from the MHRPE is the Field Test Experiment, a joint US-Russian investigation of the functional performance capabilities of ISS crewmembers at landing. Our investigator team travels directly to the landing site in Kazakhstan and tests crewmember performance within minutes after egress from the Soyuz. This is arguably the best possible simulation of crewmembers landing on Mars following a six-month transit.

HRP is also deeply involved in discussions regarding the need to continue ISS beyond its currently scheduled decommissioning date in 2020. An analysis of the HRP path to risk reduction demonstrated that after 2020 we would still need approximately 300 astronaut study participants to fully complete our

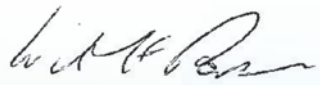


Message from the Program Manager

planned research. An ISS life extension to at least 2026 would be required to satisfy these requirements. The possibility of an extension is currently under debate within the agency and we hope to have an answer by the end of next year.

Among the most participant-intensive research areas in our path to risk reduction are those within the Behavioral Health and Performance (BHP) Element. In order to reduce the number of astronaut test subjects required to achieve the BHP risk reduction goals, HRP acquired the test facility, formerly known as the Deep Space Habitat, and recommissioned it as an isolation analog called the Human Exploration Research Analog (HERA). The HERA will also support studies sponsored by other HRP Elements and potentially used for crew and mission operations training activities in conjunction with our studies. We expect to begin the first seven-day scientific study campaigns within HERA in January 2014.

Despite budget uncertainties and a set of travel restrictions that severely limited our attendance at scientific meetings, we had a very productive year. The Program is robust, we have a well-accepted plan to achieve our risk reduction goals, and we have an outstanding set of investigators working on our scientific objectives. Regardless of the potential obstacles, we are both optimistic and committed in our focus to finding solutions that enable safe, reliable, and productive human space exploration.



William H. Paloski, Ph.D.
Program Manager

"HRP is also deeply involved in discussions... to continue ISS beyond its currently scheduled decommissioning date in 2020."

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Background

Crew health and performance are critical to successful human exploration beyond low Earth orbit. Risks to health and performance include physiologic effects from radiation, hypogravity, and planetary environments, as well as unique challenges in medical treatment, human factors, and support of behavioral health. 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.

In its eighth year of operation, HRP continues to deliver products and strategies to protect the health and safety of spaceflight crews and increase their productivity while living and working in space. Experiments continued on 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 furthered the understanding of how the space environment affects the human system. These research results contributed to scientific knowledge and technology developments that address the human health and performance risks.

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

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

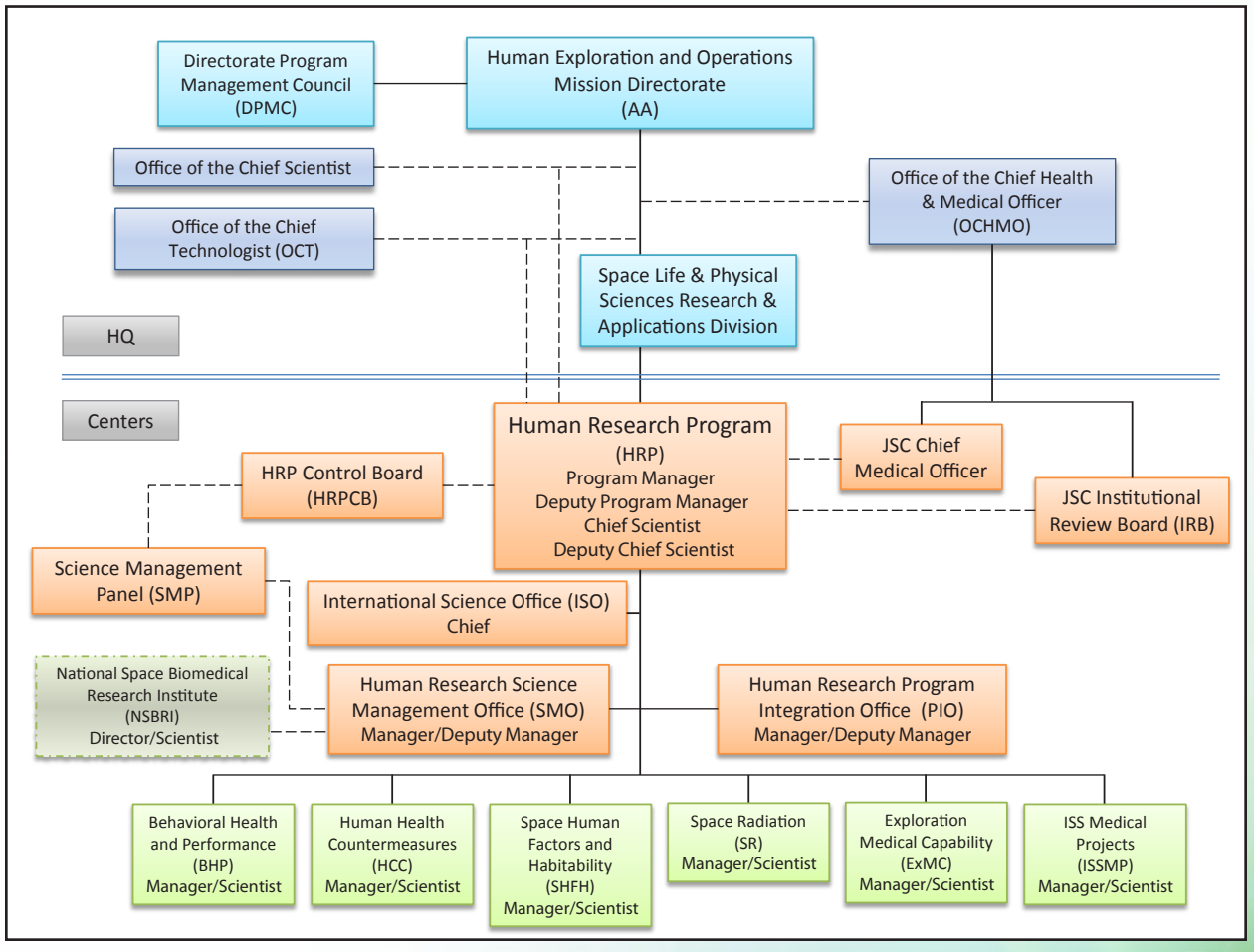
competencies necessary to enable risk reduction in the following areas: space medicine, physiological and behavioral effects of long duration spaceflight on the human body, space environmental effects, including radiation, on human health and performance and space human factors.

Program Organization

The HRP's organization is designed to support and accomplish 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.

Three offices support program and science management and provide integration across the Program. There are six Elements that comprise the Program and are focused to accomplish specific goals for



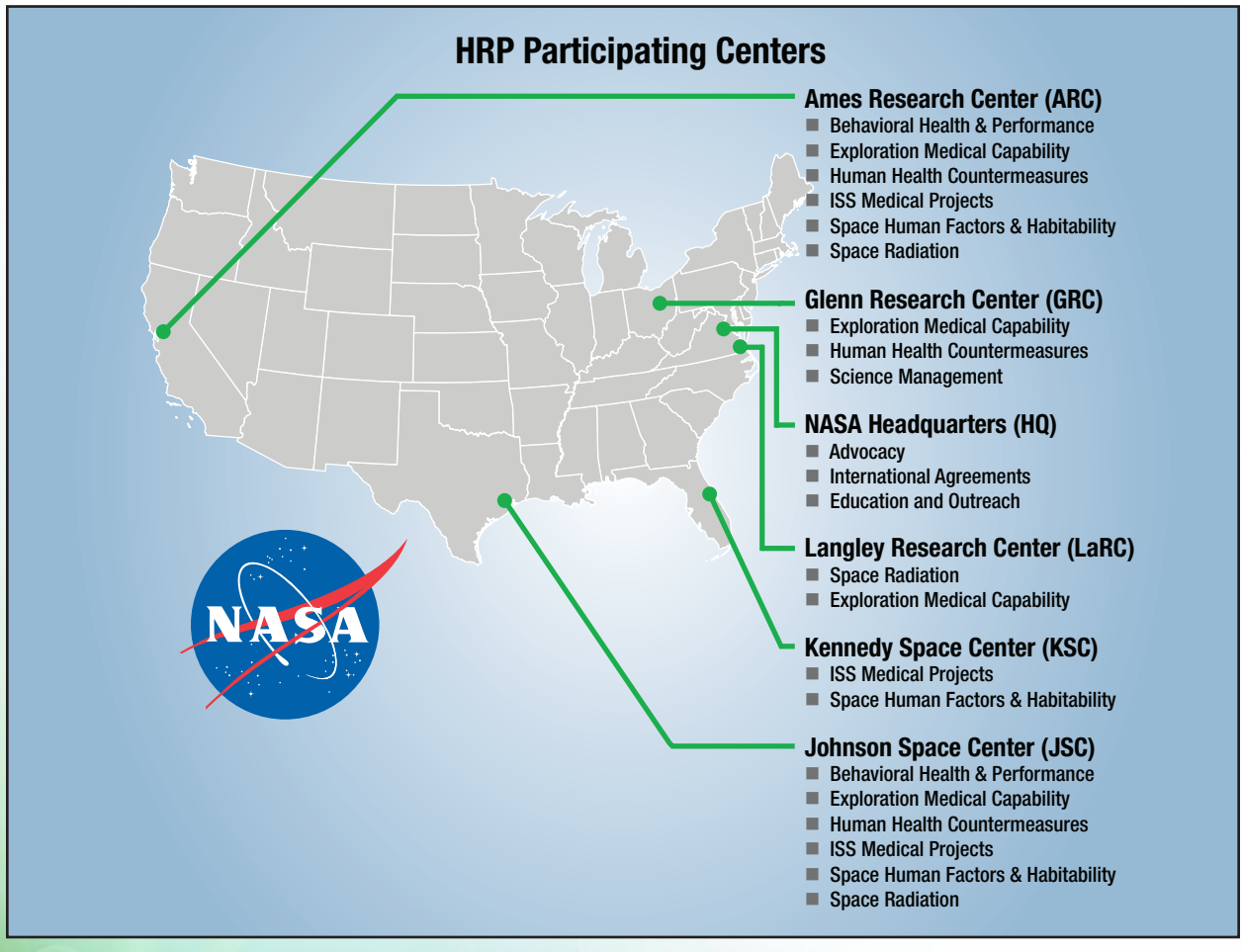
investigating and mitigating the highest risks to astronaut health and performance. The Science Management Office (SMO), International Science Office (ISO), and Program Integration Office (PIO) provide coordination of HRP activities in support of the Program Manager, Chief Scientist, and all other Program components.

The SMO 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 ISO coordinates new multi-national initiatives with the intent of increasing the availability of medical and science data among international partners (IPs), increasing test subject availability and standardizing and sharing research hardware.

The PIO provides program planning, integration, and coordination across the HRP. This office ensures close coordination of customer needs and the HRP's deliverables developed to meet those needs.

Six subject areas or Elements comprise the HRP: International Space Station Medical Projects, 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.

Each 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.

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. Additional information about the NSBRI can be found at: www.nsbri.org.

The HRP also maintains collaborative relationships with the IPs through various working groups. These relationships enhance the research capabilities of all partners and provide synergism of research efforts.

The HRP uses 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.

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	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
International Space Life Sciences Working Group (Canada, Japan, Germany, Ukraine, France, and the European Space Agency)	Encourages a unified effort among participating space life sciences communities around the world by coordinating the use of spaceflight and ground research facilities and identifying mutual interests and compatibilities
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
General Clinical Research Center and the Lerner Research Institute at the Cleveland Clinic/University of Washington	Provides facilities for bed rest and 6-degree head-down-tilt simulation along with a zero-gravity locomotion simulator in support of HRP research

Examples of HRP Partnerships and Collaborations	Benefits to Exploration
National Oceanic & Atmospheric Administration (NOAA) at the Aquarius Undersea Habitat	NASA Extreme Environment Mission Operations (NEEMO) uses this undersea habitat as a research analog
Haughton Mars Project at Devon Island managed/operated by the Mars Institute with support from the SETI Institute	Research performed in the High Arctic used as a terrestrial analog for Mars
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
Japan Aerospace Exploration Agency (JAXA)	Research on bone-related risks
Institute for Biomedical Problems (IBMP)	Coordination of the 1-year mission and functional performance Field Test Experiment
Texas Instruments and Laying the Foundation	Content and curriculum development for the HRPEO 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 HRPEO information on the Human Challenges of Space Exploration
New York State Special Olympics and The Jamestown Resource Center	Collaboration on the modification of HRPEO 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: ESA, DLR, CNES, JAXA, UK SA, ASI, NSO, FFG, and CSO; and world-wide community partners such as Infini-TO, CDTI, Technisches Museum Wien, Euro Space Center, Space Expo, Ciencia Viva, Museum.BL, Universidad Politecnica de Madrid, Tycho Brahe Planetarium, and Comision Colombiana del Espacio, and U.S. schools.	Collaboration and partnerships leading to the world-wide dissemination of HRPEO Mission X: Train Like an Astronaut physical and educational activities encouraging healthier and more nutritious lifestyles for approximately 15,000 students

Additionally, the HRP organizes and participates in international collaborative meetings and coordinates research and technology workshops. These workshops are held to inform the public about HRP research and to obtain information about investigations being conducted in the commercial and academic sectors.

International Coordination Meetings and Research and Technology Workshops

Meeting	Meeting Description
International Space Life Sciences Working Group (ISLSWG) http://www.nasa.gov/directorates/heo/slpsra/islswg.html	Works to bring agencies together by identifying their mutual interests and programmatic compatibilities, enhancing communication, and encouraging a unified effort among the participating space life sciences communities around the world.
Meeting of US-Russian Joint Working Group (JWG)	Discussed space biology and space medicine emphasizing ISS research and opportunities for collaboration, and education and outreach opportunities to inspire the next generation of scientists and physicians who will work in future human spaceflight endeavors.
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.
ISS Expert Working Group (IEWG)	Responsible for coordinating and facilitating multilateral human research on ISS. Participants include ISS program managers of all of the partner nations.
International Analog Research Working Group (IARWG)	Coordinates isolation and confinement research in analog environments across the multiple international partnering agencies.
HRP Investigators' Workshop http://www.hrpiws2013.com	Conference for researchers, funded by NASA and the National Space Biomedical Research Institute (NSBRI), to present the results of their studies.
Annual NASA Space Radiation Investigators' Workshop	Provided an opportunity for active researchers in the NASA Space Radiation Program to share the results of their work and to explore new directions of research that may benefit the NASA program.
NSBRI Symposium "Towards Integrated Countermeasures"	Participants examined the relationships between research conducted in the related areas of sensorimotor adaptation, exercise, and visual impairment and intracranial pressure.
2013 NSBRI Sponsored Working Group "The Impact of Sex & Gender on Adaptation to Space"	Working groups were divided into six areas: cardiovascular, musculoskeletal, neuro-vestibular, reproductive, immunological and behavioral. Results will be published in the *Journal of Women's Health*.

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Mission X 2013 Increases Participation by 50% Compared to Previous Year

The goal of the Mission X: Train Like an Astronaut (MX) program is to educate youth on a global scale to live healthier lifestyles and learn about human space exploration. Led by NASA, Mission X 2013 (MX13) represents the second year of a multi-year effort and has shown significant growth. Compared to the previous year, MX13 added seven additional countries and increased participation by 50%. In total, 22 countries speaking 15 different languages engaged in this international effort.

Fourteen countries hosted their own closing ceremonies, including MX13 Team USA. In addition, 12 of 22 countries participated in the International Closing Event, which was held at the European Space Research and Technology Centre (ESTEC). The ESTEC is the European Space Agency's main technology development and test center for spacecraft and space technology and is located in Noordwijk, South Holland.

MX13 participants were challenged to demonstrate their fine art skills in representing health, fitness, and space exploration in the Humans in Space Youth Art Competition. Nineteen of more than 500 submissions were awarded the Mission X Youth Art Award.

Participating countries were offered the opportunity to use pre- and post-program quality surveys that would provide data for future program improvements. Five of the 22 countries implemented these surveys and results showed a 5-10% improvement in daily physical activity and slight increases in the students' understanding of health and spaceflight topics. Several challenges remain, such as making the surveys more clear and focused on spaceflight topics. Information gained and changes made due to these quality surveys are considered a major step forward for the MX community to improve the challenge content and activities.

Continuing obstacles include financial and timing constraints. For example, the timing of the Challenge remains an issue for countries in the Southern Hemisphere, where the school year is opposite from the Northern Hemisphere's school year. However, many innovative ideas have been proposed to work around the fixed start and end dates of the challenges. Plans for MX14 are to expand the number of participants as well as highlight an International Space Station (ISS) Expedition 38 crewmember who will share a series of tips on health and fitness.

For more information, visit: trainlikeanastronaut.org

Major Program-Wide Accomplishments

2013 Human Research Program Investigators' Workshop Draws Record Attendance

The 2013 Human Research Program (HRP) Investigators' Workshop was held in February in Galveston, Texas. The theme was "ISS: Finite Duration, Infinite Possibilities" and included tutorials and panel discussions to address opportunities, processes, resources, and strategies to optimize ISS research. This annual conference serves as the main venue for investigators funded by HRP or the National Space Biomedical Research Institute (NSBRI) to present their research to NASA.

In coordination with NSBRI, scientific sessions included presentations on research progress and findings given by principal investigators from all HRP research elements. The Associate Administrator of the Human Exploration and Operations Mission Directorate at NASA Headquarters provided the keynote address. This year's workshop was the largest with 625 attendees representing five NASA field centers, 10 countries, and 117 organizations.

A total of 140 slide and poster presentations were given during 30 discipline-specific sessions and two poster sessions. A graduate student at MIT won the Graduate Student Poster Award. His poster highlighted Shape Memory Alloy Coil Actuators for use in controllable mechanical counter-pressure spacesuits. An NSBRI Postdoctoral Fellow was the winner of the Postdoctoral Fellow Award. Her research at Johns Hopkins University centers on mitigating neurobehavioral vulnerabilities to space radiation.

This year's HRP Investigators' Workshop was the largest with more than 625 attendees. The HRP Program Manager addressed attendees during the opening session.

The meeting program and abstracts can be viewed online at: http://www.hrpiws2013.com.

Unique Human Exploration Research Analog (HERA) Acquired by HRP

The Human Exploration Research Analog (HERA), formerly known as the Deep Space Habitat, was transferred from the JSC Engineering Directorate to HRP in FY2013. This unique modular three-story habitat was designed and created through a series of university competitions and was previously used in the Desert Research and Technology Studies in the Arizona desert.

The HERA will provide a high-fidelity research venue for scientists to use in addressing risks and gaps associated with human performance during spaceflight. Historically, the habitat was used for exploration engineering systems demonstrations. In its new role, the HERA will serve as an analog for simulation of isolation, confinement, and remote conditions of mission exploration scenarios.

Studies suitable for this analog may include behavioral health and performance assessments, communication and autonomy studies, human factors evaluations, and exploration medical capabilities assessments and operations.

HRP's path to risk reduction demonstrated that after 2020 investigators would still need approximately 300 astronaut study participants to fully complete their planned research. It is expected that the use of HERA will reduce the requirements for spaceflight resources in conducting these types of studies.

HERA's modular structure includes a central core laboratory segment with an adjoining second and third story devoted to living quarters. HRP investigators will use this full-size habitat as an analog for future exploration-class missions.

2012 NRA Research Selections Include Grants Representing 18 Institutions

HRP's priority is to promote full and open competition for research and technology investigations through annual research solicitations issued by both NASA and NSBRI. Additionally, when appropriate, HRP may use directed research investigations to accomplish the desired research. Currently, 76% of HRP research is derived from open competition, while 24% is directed.

In response to the 2012 NASA Research Announcement (NRA) for "Research and Technology Development to Support Crew Health and Performance in Space Exploration Missions," HRP and NSBRI selected 23 research proposals representing 14 states and 18 institutions. These selections resulted in a combined grant award value of approximately $17 million over a span of one to three years. Proposals were solicited from academia, industry, and government laboratories, and were judged for scientific merit by non-NASA technical experts.

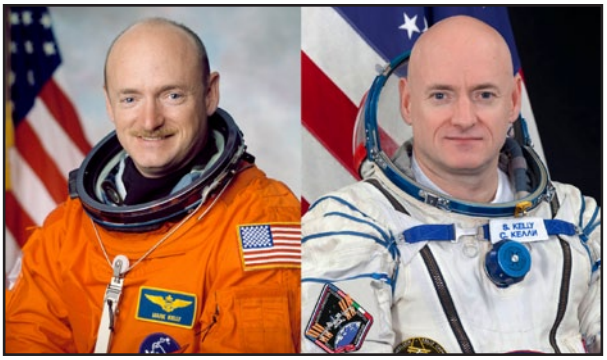
Focus areas for the NRA were sensorimotor impairment and space motion sickness; spaceflight-induced cardiovascular disease; computational models of cephalad fluid shifts; spaceflight biochemical profile; maintenance and regulation of team function and performance over extended durations; neurobehavioral and psychosocial factors; smart medical systems and technology; and development of safety and efficiency metrics for human-automation systems. HRP also requested proposals for short-term investigations or technologies, called omnibus proposals, which would provide innovative approaches to mitigating any of the risks defined in the HRP Integrated Research Plan. The IRP can be found within the HRP Human Research Roadmap at: http://humanresearchroadmap.nasa.gov.

New HERO NRA Format Allows for Greater Solicitation Flexibility Throughout Fiscal Year

In 2013, HRP transitioned to a new NRA format to be more responsive and flexible, and enabling solicitations throughout the year. Historically, one research announcement was issued in July, resulting in selection of proposals in April of the following year. The Human Exploration Research Opportunities (HERO) NRA is a new solicitation that will remain open year-round, with new research opportunities, or appendices, being issued as needed.

In July, the HERO NRA, NNJ13ZSA002N, was issued jointly with NSBRI to announce four research opportunities which included: the NASA Flagship proposals, NSBRI Flagship proposals, NASA Omnibus proposals, and a Twin Astronaut Studies special topic. Proposals were solicited for a wide range of disciplines. In September a record number of 211 Step-1 proposals were received. HRP received 73 Flagship and 79 Omnibus proposals and NSBRI received 59 Flagship proposals. In October, 141 Step-1 proposals were invited to submit Step-2 proposals. Final selections will be announced in April 2014.

The HERO NRA included the solicitation, "Differential Effects on Homozygous Twin Astronauts Associated with Differences in Exposure to Spaceflight Factors." This opportunity emerged from NASA's decision to fly veteran astronaut Scott Kelly



Identical twin astronaut brothers, Mark Kelly (left) and Scott Kelly (right), are subjects of a new research solicitation. Mark accumulated 54 days in orbit during shuttle flights and Scott will have logged a total of 540 days in orbit at the conclusion of his one-year flight.

aboard the ISS for a period of one year beginning in March 2015, while his identical twin brother, retired astronaut Mark Kelly, remains on Earth. Researchers will be provided opportunities to propose limited, short-term investigations examining the differences associated with differential exposure to spaceflight conditions in identical twin astronauts.

The scientific community's response to this call for proposals was very positive with 40 proposals being received from a number of prominent U.S.-based researchers. Proposals deemed both responsive and implementable will enter a full scientific peer review with selections announced in early 2014.

2013 Space Radiation NRA Released and Selections Announced

The Space Radiation Program Element released its 2013 NRA, titled "Ground-Based Studies in Space Radiobiology," in February and received 51 Step-2 proposals in response to the solicitation. Eleven research proposals representing 8 states and 11 institutions were selected, and the investigators will seek to use new experimental approaches in understanding the effects of exposure to space radiation on risks of cancer, heart and circulatory disease, and decrements in long-term cognitive function.

HRP Selects Small Businesses for Awards Utilizing NASA SBIR Program

The NASA Small Business Innovation Research (SBIR) Program is targeted at small businesses and is designed to bring innovative ideas to HRP. The SBIR Program Management Office released the 2014 SBIR Phase 1 solicitation in November 2013. The four HRP subtopics included in the solicitation were Next Generation Oxygen Concentrator for Medical Scenarios, Inflight Calcium Isotope Measurement Device, Objective Sleep Measures for Spaceflight Operations, and Advanced Food Technology. Awards will be announced in April 2014.

In April 2013, six Phase 1 awards were selected from the five HRP subtopics included in the 2012 solicitation. Topics were: Portable Activity Monitoring System; Medical Suction Capability; Innovative Technologies for a Virtual Social Support System for Autonomous Exploration Missions; Advanced Food Systems Technology; and In-flight Biological Sample Analysis.

Additionally in 2013, two SBIR projects were selected for Phase 3 funding. The goal of the Individualized Behavioral Health Monitoring Tool by Pulsar Informatics, Inc. is to deliver a tool that unobtrusively integrates all available behavioral measures collected during a mission to provide a dashboard of behavioral health indicators. The Human Factors Evaluation Automated Tool by TiER1 Performance Solutions will help engineers and program managers identify and avoid potential human factors problems early in the design process.

In May, the NASA Small Business Technology Transfer (STTR) Program selected two 2011 Phase 2 awards supporting HRP research for the Human Health Countermeasures and Behavioral Health Elements. The STTR awards are similar in duration and amounts as SBIR awards but require small businesses to partner with nonprofit research institutions to move ideas from the laboratory to operations.

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Space Cancer Risk Model Wins JSC 2013 Software of the Year Award

NASA's current missions to the ISS and future exploration missions present challenges in protecting astronauts from radiation risks. These risks arise from a variety of sources, including solar particle events and galactic cosmic rays. Equally varied are the serious early- and late-risks of health effects caused by radiation exposure, such as radiation sickness and cancer. Other possible effects include central nervous system damage, cataracts, cardiovascular damage, heritable effects, impaired wound healing, and infertility.

A team of seven scientists from the Space Radiation Element and the Universities Space Research Association (USRA) developed the new NASA Space Cancer Risk (NSCR) projection model, which was released in December 2012. The tool evaluates the cancer risks, including the level of uncertainty, for astronauts from exposure to solar particle events and galactic cosmic rays. The NSCR model originated from recommendations of the National Council on Radiation Protection and Measurements, with revisions from the latest analysis of human radio-epidemiology data. The model was independently reviewed by the National Research Council in 2012.

NSCR's main applications are ISS mission risk assessments and planning for future exploration missions to the moon, near-Earth objects, or Mars. In addition, an important ground-based capability developed for NSCR is the evaluation of cancer risks from aviation radiation exposures and medical diagnostic exposures, including X-rays and CT scans.

The NSCR model was the recipient of the 2013 JSC Software of the Year Award and is located at: http://spaceradiation.usra.edu/irModels

In-Flight VO_2Max Testing Leads To Recommendations for Crew Fitness

Long-duration spaceflight is associated with physiologic changes in the body similar to those of disuse or detraining. One of these changes is a decline in aerobic fitness or conditioning. A proven measure of such fitness is maximum oxygen uptake (VO_2max), also known as aerobic capacity. While on the ISS, astronauts exercise for about one hour per day in an attempt to maintain their aerobic capacity.

For the first time, HRP researchers directly measured VO_2max during long-duration spaceflight in 14 astronauts. Each astronaut's VO_2max was measured before flight, once a month during flight, and after flight using specially designed hardware. Subjects rode on a cycle ergometer using a protocol that started with a warm-up, followed by incremental increases in workload that ended in a maximal ef-

An ISS crewmember cycles on the ergometer while performing a VO_2max test. This method of testing involves capturing all of the expired 'breath' which is then analyzed.

fort. During the test, astronauts wore a nose clip and breathed through a mouthpiece so that all of the expired air was analyzed for oxygen and carbon dioxide, from which VO_2max is measured.

On average, their aerobic capacity decreased by 17% after the second week of flight and tended to slowly increase or stay the same through the remainder of the mission. Initial postflight values were still depressed by an average of 15%. After 30 days of reconditioning, their VO_2max fully recovered.

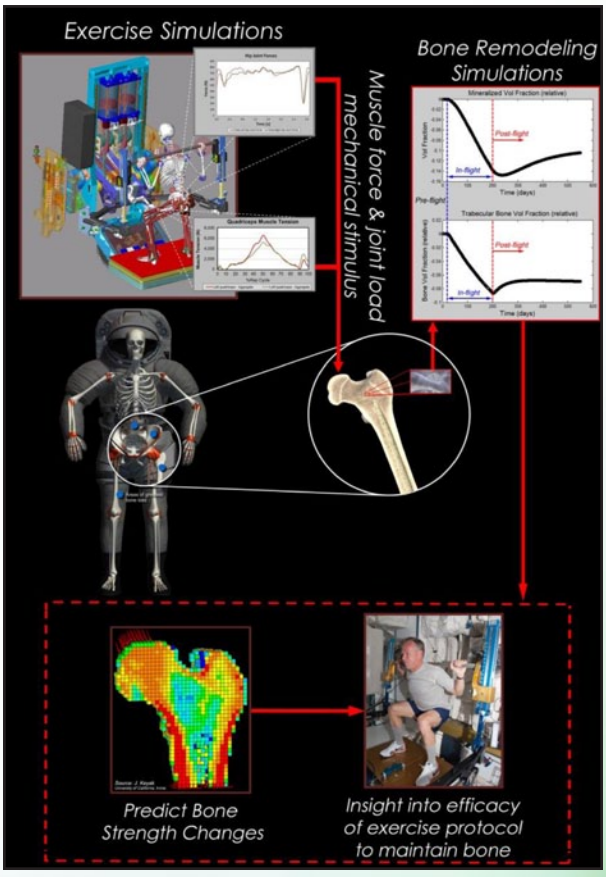
The study findings lead to several recommendations: exercise sooner, increase intensity, and improve testing. Aerobic exercise countermeasures should start as soon as possible after a crewmember arrives on the ISS, preferably in the first few days. Also, the intensity of the existing exercise countermeasures should be increased. Importantly, the testing strategy should be modified because changes in VO_2max could not be accurately detected using the standard test based on heart rate during submaximal exercise.

Software Simulates Effects of Exercise in Preventing Bone Loss

Astronauts lose a significant amount of bone in the weight-bearing portions of their skeleton during spaceflight. Crewmembers exercise throughout their mission in an attempt to simulate skeletal loading such as they experience on the ground. The Digital Astronaut Project (DAP) has coupled two software modeling efforts in an attempt to quantify the effects of such exercise-induced skeletal loading.

One model simulates the joint torque and muscle forces exerted on critical bone areas when performing deadlift and normal squat exercises using the Advanced Resistive Exercise Device (ARED). The companion model simulates the effect of exercise to reduce bone changes at the femoral neck. Their combined results quantify the effect of prescribed exercise and exercise devices on preserving bone.

To quantify the effects of skeletal loading, DAP is also developing a bone remodeling software model. This model will accept, as input, a history of load-



DAP models help researchers assess spaceflight musculoskeletal risks and enhance countermeasure development.

ing due to muscle and joint force on bone and can, as output, predict remodeling in the bone region under the influence of the applied stress. The model includes both trabecular bone—the inner sponge-like bone—and cortical bone, the smooth, compact outer layer of bone. The two kinds of bone tend to respond differently.

Because hip fractures can be debilitating, development of the initial model focused on the neck of the femur, which is the narrow portion of the thigh bone just below the ball end. DAP completed an initial model of bone loss due to skeletal unloading in this region. The model's predictive capability was validated against bone mineral density measurements acquired from bed rest control subjects.

Recommendation of Safe Lunar Dust Exposure for Long-term Lunar Operations

Although Apollo astronauts were exposed briefly to lunar dust and reported it to be irritating at times, studies of its toxicity were limited. In 2005, as NASA anticipated a return to the moon, a group of experts convened to determine how much uncertainty existed in estimating safe human exposures to lunar dust. The Lunar Airborne Dust Toxicity Assessment Group (LADTAG) determined that a 300-fold uncertainty existed in establishing safe long-term exposure levels. Uncertainty existed because the dust might have highly reactive surfaces, exhibit unusual mineralogical properties, and consist of ultrafine grains that would enhance toxicity, which, for the study's purposes, is injury to the tissues of the lung.

Under the guidance of LADTAG experts, lunar geologists and inhalation toxicologists developed a two-tiered approach to investigate the inherent toxicity of lunar dust. A parent sample returned by Apollo 14 was used to isolate native dust of respirable size. Respirable native dust constitutes only a few percent by mass of lunar soil, and is of great concern because it can be inhaled deeply into the lungs. In addition,

JSC scientists study the potential health effects of lunar dust using samples brought back by the Apollo 14 mission.

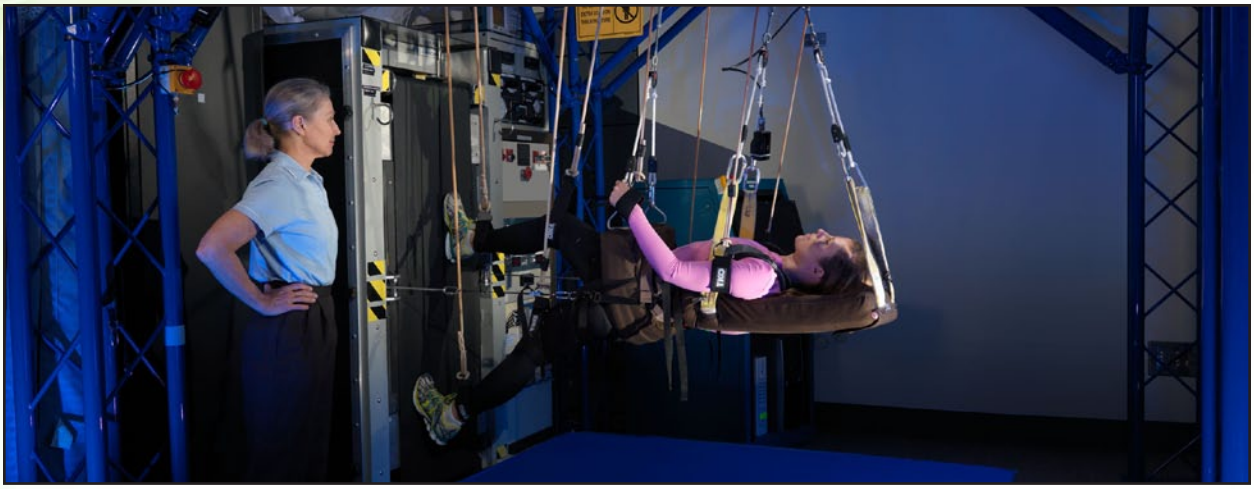
a small portion of the parent sample was ground to respirable size to simulate activation of the surface of the dust, as might occur on the lunar surface.

The first phase demonstrated the toxicity of ground dust and native dust was similar when laboratory animals were exposed to the dust by intratracheal installation. The dusts were found to be of intermediate or moderate toxicity when compared to the control groups.

In phase two of the experiments, laboratory animals were exposed periodically by nose-only inhalation to one form of the ground dust. Their lungs were then examined and an independent risk assessment of the instillation and inhalation results was made.

The results of the studies led to a recommended safe exposure estimate of 0.5 mg/m^3 as a safe concentration of dust in a habitable environment for periodic exposures of up to six months. The original 300-fold gap in uncertainty was reduced to essentially no uncertainty. However, the recommended exposure is likely a conservative value and should not be applied to dust from unusual locations on the moon. In FY13, this research was published in a series of three papers in Volume 25 of the journal *Inhalation Toxicology* which can be accessed at: http://informahealthcare.com/journal/iht.

International Space Station Medical Projects Element



Overview

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

The objectives of ISSMP are to maximize the utilization of the ISS and to develop and verify strategies to ensure optimal crew performance. The ISSMP also enables the development and validation of physical, pharmacologic, and nutritional countermeasures that influence mission success or crew health.

ISSMP flight operations support ISS research investigations by coordinating pre-, in-, and postflight activities including hardware development and certification; providing training of crewmembers and ground controllers; monitoring real-time on-orbit experiment and hardware operations; and facilitating the transfer of data to research investigators.

On-orbit, ISSMP provides the Human Research Facility which includes hardware that enables human research and is available to investigators who wish to conduct human physiological research. 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 International Partners to develop integrated mission-specific science complements for investigations and to negotiate schedules and usage agreements, and crewmember participation. ISSMP provides complete integration support for multiple flight vehicles including the Russian Soyuz and Progress, European, Japanese, and commercial launch vehicles.

In its ground-based role, ISSMP's Flight Analogs Project (FAP) provides NASA with a terrestrial research platform to complement spaceflight investigations. Flight analog testing is vital to identify, understand, and minimize spaceflight-related risks, to ensure the health and productivity of humans during spaceflight. Some example analog environments are head-down-tilt bed rest and extreme environments such as NASA Extreme Environment Mission Operations (NEEMO), Haughton Mars Project (HMP) and the Desert Research and Technology Studies (RATS).

To learn more: http://www.nasa.gov/exploration/human-research/elements/research_info_element-issmp.html.

During FY2013, ISSMP coordinated flight research supporting ISS Increments 34-38. Research accomplishments include the completion of four flight studies and nine continuing studies. Also in FY2013, nine new investigations began flight operations, three began development of flight requirements to support future missions, and five are undergoing feasibility assessments, awaiting a future select-for-flight decision. The following table lists all ISSMP active flight experiments and status to date.

Investigation Title	Ops Title	Subjects		Status
		Required	Participation Through Increment 37	
Investigations Continuing Flight Operations in Fiscal Year 2013				
NASA Biological Specimen Repository	Repository	All	33	Recruitment continues for all future ISS missions.
Physiological Factors Contributing to Changes in Post-Flight Functional Performance	FTT	13 Shuttle 13 ISS	7 Shuttle 12 ISS	Completed data collection for short duration shuttle subjects. Continuing data collection with ISS crewmembers and expected to complete in 2014.
Dietary Intake Can Predict and Protect Against Changes in Bone Metabolism During Spaceflight and Recovery	Pro K	16	16	Final subject expected to participate during the ISS Increment 37-38 mission.
Psychomotor Vigilance Self Test on ISS	Reaction Self Test	24	23	In-flight operations continued throughout missions in 2013.
Integrated Resistance and Aerobic Training Study	Sprint	20 Control 20 Active	4 Active 2 Control	In-flight operations continued throughout missions in 2013.
Behavioral Issues Associated with Long Duration Space Expeditions: Review and Analysis of Astronaut Journals	Journals (6 crew)	10	6	Began with data collection in Increments 29/30. Previously conducted when crew size was three. Ten additional subjects with crew size increase to six.
Bisphosphonates as a Countermeasure to Space Flight Induced Bone Loss	Bisphos-phonates (CONTROL)	10	5	Participation in the control group began with Increment 31.
Risk of Intervertebral Disc Damage After Prolonged Spaceflight	IVD	12	2	Pre- and postflight investigation began pre-flight data collection with Increment 33 in FY2012.
Assessment of Operator Proficiency following Long-Duration Spaceflight	Manual Control	8	3	Pre- and postflight investigation began pre-flight data collection with Increment 33 in FY2012.
Investigations with Initial Flight Operations in Fiscal Year 2013				
NASA Biochemical Profile Project	Biochem Profile	All USOS	1	Selected for flight in 2012. Data collection begins with the ISS Increment 37 crewmember.

Investigation Title	Ops Title	Subjects		Status
		Required	Participation Through Increment 37	
Assessing the Impact of Communication Delay on Behavioral Health and Performance: An Examination of Autonomous Operations Utilizing the ISS	Comm Delay Assessment	3	0	Flight operations are expected to occur during Increment 39/40. In-flight data collection is expected to be completed during 2014.
Occupational Risk Surveillance for Bone: Pilot Study-Effects of In-Flight Countermeasures on Sub-Regions of the Hip Bones	Hip QCT	10	9	Selected for flight in 2012. Pre- and postflight study will recruit subjects that have already flown on ISS utilizing data collected from a previous investigation.
Study of the Impact of Long-Term Space Travel on the Astronaut's Microbiome	Microbiome	9	3	Selected for flight in 2012. Flight operations are in progress with ISS Increment 35/36.
Spaceflight Effects on Neurocognitive Performance: Extent, Longevity and Neural Bases	Neuro-Mapping	13	0	Selected for flight in 2012. In-flight data collection is planned to start with the Increment 39/40 crew in 2014.
Prospective Observational Study of Ocular Health in ISS Crews	Ocular Health	12	3	Selected for flight in 2012. In-flight data collection began with ISS Increment 35/36.
The Effects of Long-Term Exposure to Microgravity on Salivary Markers of Innate Immunity	Salivary Markers	6	1	Selected for flight in 2012. Data collection is scheduled to begin during the ISS Increment 37/38.
Sonographic Astronaut Vertebral Examination	Spinal Ultrasound	6	6	Began in-flight operations in 2013 starting with Increment 34. In-flight data collection is expected to complete in 2014.
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	12	0	Selected for flight in 2012. Data collection is scheduled to start during the ISS increment 37/38 mission.
Investigations Completing In-Flight Operations in Fiscal Year 2013				
Cardiac Atrophy and Diastolic Dysfunction During and After Long Duration Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capacity, and Risk of Cardiac Arrhythmias	Integrated Cardio-vascular	12	13	Final data collection completed in FY2013.

Investigation Title	Ops Title	Subjects		Status
		Required	Participation Through Increment 37	
Maximal Oxygen Uptake During Long Duration ISS Missions	V02max	12	14	Study completed with landing of the Increment 32/33 crew in early FY2013.
Biomechanical Analysis of Treadmill Exercise on the ISS	Treadmill Kinematics	6	7	Flight operations began during Increment 27/28 and completed with landing of the 32/33 crew in early FY2013.
Nutritional Status Assessment	Nutrition	30	32	Subject number increased from 24 to 30 in 2011. Recruitment of subjects completed in 2012; in-flight data collection completed during FY2013.
Investigations Initiating Flight Development Activities in Fiscal Year 2013				
Quantification of In-flight Physical Changes – Anthropometry and Neutral Body Posture	Body Measures	12	1	Selected for Flight in 2013. Study will begin with Increment 37/38 Crew.
Factors Contributing to Food Acceptability and Consumption, Mood and Stress on Long-term Space Missions	Astro Palate	8	0	Selected for Flight in 2013. Informed consent briefings begin with the ISS Increment 41/42 Crew.
Individualized Real-Time Neurocognitive Assessment Toolkit for Space Flight Fatigue	Cognition	6	0	Selected for Flight in 2013. Informed consent briefings began with the ISS Increment 41/42 Crew.
Investigations Awaiting Select for Flight Decision				
Fluid Shifts Before, During and After Prolonged Space Flight and Their Association With Intracranial Pressure and Visual Impairment	Fluid Shifts	10	0	Study completed peer review in 2013 and is awaiting Select for Flight Approval.
Assessing Telomere Lengths and Telomerase Activity in Astronauts	Telomeres	10	0	Study selected by HRP and undergoing ISSMP Feasibility Assessment.
Habitability Assessment of International Space Station	ISS Habitability	TBD	0	Study selected by HRP and undergoing ISSMP Feasibility Assessment.
Human Cerebral Vascular Autoregulation and Venous Outflow In Response to Microgravity-Induced Cephalad Fluid Redistribution	Cephalad Fluid Re-distribution	10	0	Study selected by HRP and undergoing ISSMP Feasibility Assessment.

Investigation Title	Ops Title	Subjects		Status
		Required	Participation Through Increment 33	
Effects of Long-duration Microgravity on Fine Motor Skills: 1-year ISS Investigation	Fine Motor	TBD	0	Study selected by HRP and undergoing ISSMP Feasibility Assessment.
Recovery of Functional Sensori-motor Performance Following Long Duration Space Flight	Field Test	TBD	0	Study selected by HRP and undergoing ISSMP Feasibility Assessment.

New RFID Tagging Capability to Improve ISS Consumable Tracking

The ISSMP team developed a unique stowage drawer for the ISS Human Research Facility (HRF) racks allowing ground personnel to remotely determine the contents utilizing radio-frequency identification (RFID) technology. ISSMP has followed the capabilities and progress in RFID development with the goal of capitalizing on technology to improve ISS consumables tracking and inventory management.

Collaborations between ISSMP and the Engineering Directorate at JSC resulted in an opportunity to upgrade an existing stowage drawer with RFID capability for the HRF Racks. The hardware was delivered to the ISS in FY13 with activation and checkout planned for 2014. Two additional drawers are planned to be delivered in the next several years.

The drawer includes four antennas, a RFID Reader electronics box, and software to make the system operational for multi-drawer application. In addition to the drawer, ISS Program RFID tags were added to pantry items that will be stowed in the drawers. Each drawer may contain up to 100 tags, representing thousands of experiment consumables including blood and urine tubes, saliva vials, electrodes, ultrasound gel, swabbing tubes, and batteries.

Currently, ISS crewmembers spend two to three hours performing manual inventories of these supplies. Once the utility drawers are fully operational, ground controllers will be able to read the contents of the drawer without crew involvement, providing a more accurate insight into the status of HRP flight consumables.

FLIGHT ANALOGS PROJECT (FAP)

Flight analogs can be used to simulate the effects of little or no gravity on the human body. By eliciting on Earth physiologic responses similar to those experienced by the human body in space, scientists can test and refine theories and procedures to deepen our understanding and develop countermeasures to protect humans from the effects of space travel.

FAP supports the accomplishment of HRP objectives by investigating, acquiring, utilizing, and operating high-fidelity ground analogs of the space exploration environment. These ground analogs are utilized to conserve spaceflight resources while expeditiously and efficiently addressing research questions for future manned exploration missions. Two high-fidelity facilities maintained by FAP are the Flight Analog Research Unit (FARU) and the Human Exploration Research Analog (HERA).

FAP assists researchers by characterizing current and potential analogs, evaluating their relevance and similarity to spaceflight conditions, and matching the characteristics of analogs to requirements for research. The use of ground analogs, such as bed rest, is essential to these efforts because access to the resources required to conduct studies in space is very

limited, and the expense of flight studies is significantly greater than the expense of ground studies. Flight analog testing will become more and more critical to NASA to validate countermeasures, given the few opportunities to use flight platforms such as the International Space Station (ISS) and the limited number of crewmembers per Expedition.

The following chart shows characteristics of analogs used by FAP:

Analog Characteristics	FARU - UTMB	NEEMO	Devon Island / HMP	Antarctica	Desert RATS	Human Related Chamber Complex	HERA
Environment/Terrain External to Habitat							
Desert (may include Arctic desert)			●	●	●		
Island			●				
Ice sheet				●			
Sub-ocean		●					
Other	●					●	●
Extreme Environment Features							
Hypoxia						●	
Hyperbaric						●	
Atypical day length			●	●			●
High humidity		●					
High temperature					●		
Low temperature			●	●	●	●	
Characteristics							
Confinement within habitat	●			●		●	●
Crew hierarchy (Commander, etc.)		●					●
Microgravity simulation (0g)	●	●					
Lunar gravity simulation (1/6g)	●	●					
Mars gravity simulation (3/8g)		●					
Difficult or limited logistics		●	●	●			●
Isolation from outside world		●	●	●		●	●
Limited local infrastructure		●	●		●		●
Remote communications			●	●		●	●
Autonomous operations		●	●	●		●	●
Autonomous care or "telemedicine"		●	●	●			●
Moon/Mars field or EVA activities		●	●		●		●
Lunar surface simulation			●		●		●
Martian surface simulation			●		●		●

For more information about the Flight Analogs Project, please visit: http://www.nasa.gov/centers/johnson/slsd/about/divisions/spacemed/project/flight-analogs.html

Human Exploration Research Analog (HERA) Outfitting and Validation

The HERA is a three-story habitat located at Johnson Space Center (JSC) and includes a simulated airlock, hygiene module, galley, flight simulator, and other task performance workstations. Currently, the HERA represents an analog for simulation of isolation, confinement, and remote conditions of mission exploration scenarios. Studies suitable for this analog may include behavioral health and performance assessments, communication and autonomy studies, human factors evaluations, and exploration medical capabilities assessments.

During the acquisition and initial outfitting of HERA, FAP worked to ensure the facility met all requirements for conducting research. A continuous 3-day engineering and operations test was completed in the fall of 2013, to gauge readiness to support upcoming research missions. The facility was assessed for operational readiness, including overnight crew habitation and the ability to conduct research.

Campaigns of incremental duration are planned to start by early 2014. A campaign is defined as one integrated protocol with one primary mission scenario and will consist of multiple missions in order to meet study subject requirements. Mission durations are planned from 7 days up to 30 days.

Flight Analog Research Unit Bed Rest Campaign Continues Through FY2013

Of all the potential challenges crewmembers encounter in the space environment, microgravity has proven to be one of the most difficult to mimic in an experimental setting. HRP researchers and engineers are studying bed rest as an experimental analog for spaceflight because extended exposure to a head-down-tilt position can duplicate many of the effects of a low-gravity environment.

The FARU is a dedicated bed rest study facility at the University of Texas Medical Branch (UTMB) in Galveston, Texas, and is maintained by FAP. The facility is equipped with beds that can be adjusted into positions that reproduce the effects of different gravity fields on the human body. By manipulating

these and other variables, the FARU team works to gather data and develop countermeasures to ease the effects of reduced gravity on crews of future long-duration missions.

Bed rest studies focus on multiple scenarios including the musculoskeletal and psychological effects of long-term confinement to a reduced-gravity environment. The FARU functions under a set of uniform operating conditions to ensure consistency across all studies and scenarios. Additionally, individual investigations may be combined into integrated studies to maximize participant usage and facility resources.

Investigations at the FARU in FY2013 and Continuing into FY2014

Investigation Title	Investigator	Subject Requirements		
		Required N	Completed in FY2013	Planned for FY2014
Physiological Factors Contributing to Post-flight Changes in Functional Performance: Bed Rest Analog Study (FTT)	Bloomberg	24	12	8
Integrated and Resistance and Aerobic Training Study - Bed Rest (iRATS)	Ploutz-Snyder	24	12	8
Testosterone Supplementation as a Countermeasure Against Musculoskeletal Losses During Space Exploration	Urban	24	12	8
Effects of Retro Nasal Smelling, Variety, and Choice on Appetite and Satiety	Hunter	16	9	5
Bed Rest as a Spaceflight Analog to Study Neurocognitive Changes: Extent, Longevity, and Neural Bases	Seidler	16	5	11
Automated Detection of Attitudes and States through Transaction Recordings Analysis (AD ASTRA) Bed Rest Analog	Miller	15	6	9
Integrated and Resistance and Aerobic Training Study - Bed Rest (iRATS) with Flywheel	Ploutz-Snyder	8	n/a	8
FAP Standard Measures	Cromwell	n/a	12	Collected on all long-duration subjects

Overview

The radiation environment in space differs significantly from the types of radiation humans encounter on Earth. Unlike gamma-rays, X-rays, and other terrestrial forms of radiation, space radiation contains high-energy particles that can cause fundamental cellular changes in any living matter it encounters, including human tissue and organs. As a result, space radiation poses a number of significant health and safety risks for crewmembers, including the possibility of cancer, visual disorders, radiation sickness, damage to the central nervous system, and potential hereditary effects. 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.

The main sources of space radiation are galactic cosmic rays (GCRs), which are particles that consist of protons and electrons trapped in Earth's magnetic field, and solar particle events (SPE). GCRs permeate interplanetary space and include particles with high ionizing energy. 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 the heavy ions' significantly greater ionizing power. This strong ionizing power leads to 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.

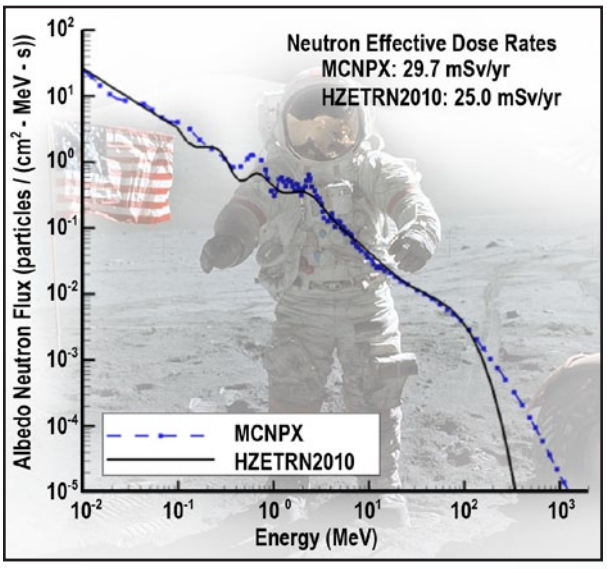
Health risks from space radiation may include an increased incidence of cancer, acute radiation syndrome, degenerative tissue damage leading to diseases such as heart disease and cataracts, and central nervous system (CNS) damage. Cancer risks pose the largest challenge for exploration. The uncertainties 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. For the CNS and degenerative risks, there are uncertainties in the dose thresholds and latency.

Research is needed to optimize radiation protection practices and countermeasures. The results of space radiation studies will provide a scientific basis to accurately project and mitigate health risks from space radiation. Additionally, research in radiobiology and physics guides risk assessment and protection strategies. Findings from these studies will provide tools for evaluating shielding recommendations as well as requirements for storm shelters and early warning systems for solar particle events. To read more about the Space Radiation Element, please visit: http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-srpe.html.

Baseline Lunar Neutron Environmental Model added to OLTARIS Website

OLTARIS (On-Line Tool for the Assessment of Radiation in Space) is a web-based space radiation design and analysis tool available for assessing the effects of space radiation for various spacecraft and mission scenarios involving humans and electronics. Lunar missions encounter neutron exposures that are estimated at about 20% of the effective radiation dose; therefore, accurate quantification of radiation exposures on the moon's surface is essential for cancer and degenerative risk projection models.

To meet this need, OLTARIS has been updated to include the capability to compute lunar surface exposures to radiation during extravehicular activities or within a habitat. The new functionality utilizes nuclear physics and transport improvements to the HZETRN (High Charge [Z] and Energy Transport) space radiation transport code to accurately calculate forward secondary and backscattered albedo neutrons. Albedo neutrons are created by the interaction of GCR, SPE, and other space radiations as they enter a planetary atmosphere. They are emitted back toward space and add to the radiation dose received by humans on the planetary surface. The lunar neutron environment can be downloaded separately and is implemented as a function of solar activity. Future work may include adaptation of the capability for asteroid missions. The OLTARIS website may be found at: https://oltaris.larc.nasa.gov.



Astronauts are exposed to radiation during lunar missions from albedo neutrons. The overall exposure is a combination of direct high-energy particle impacts and secondary impacts including neutron backscatter from the lunar surface.

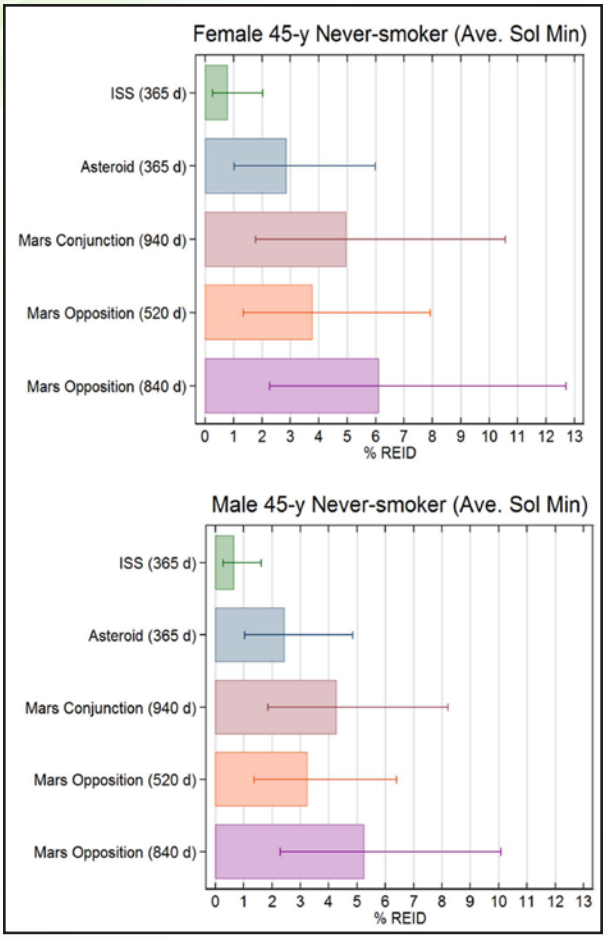
"How Safe Is Safe Enough? Radiation Risk for a Human Mission to Mars" Published

The overall space radiation exposure that astronauts will experience during a manned mission to Mars poses a significant challenge. In 2010, NASA completed a model, known as the NASA Space Cancer Risk (NSCR) model, for evaluating space radiation cancer risks, for application to exploration mission trade studies and for evaluating crew risks for missions on the International Space Station (ISS).

In FY2013, researchers used the new NSCR model to evaluate the radiation risks and uncertainties for Mars and other exploratory missions. Results include the first estimates of the combined risks for cancer and circulatory diseases for a Mars mission, as well as discussion of avenues for risk mitigation that include considerations for solar cycle timing, individual sensitivities, and biological countermeasures.

NASA's radiation standard limits astronaut exposures to a 3% risk of exposure induced death (REID) at the upper 95% confidence interval of the risk estimate. Fatal cancer risk was previously considered the dominant risk for GCR, however recent epidemiological analysis of radiation risks for circulatory diseases allow for predictions of REID for circulatory diseases to be included with cancer risk predictions for space missions.

These findings were published in the *PLOS ONE* (Public Library of Science) journal in October 2013. Members of the public can view the article online at: http://www.plosone.org/article/info:doi/10.1371/journal.pone.0074988.



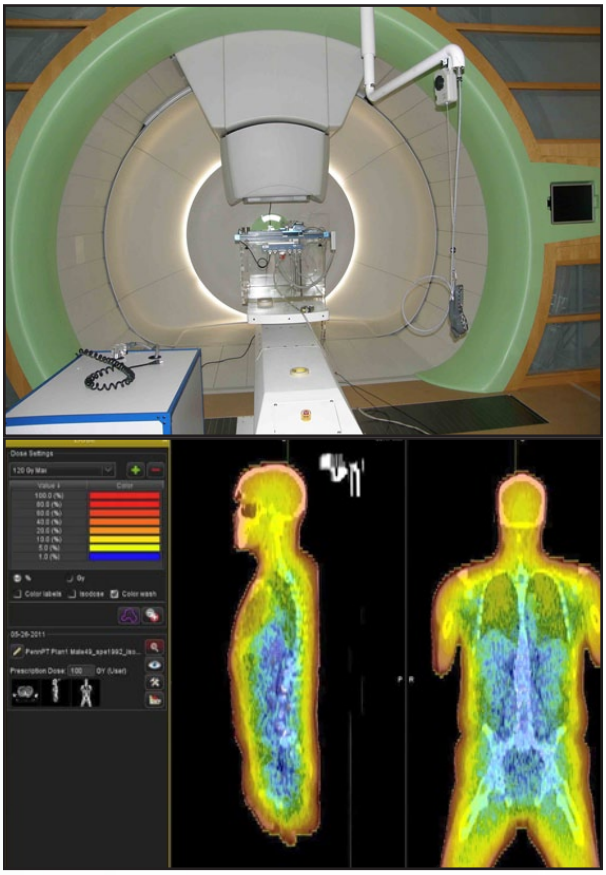
This chart shows the increasing risk of exposure-induced death (REID) from cancer and circulatory diseases for multiple exploration missions. Calculations assume specific aluminum shielding for a transit vehicle and a Martian surface habitat.

Center for Acute Radiation Research Completes 5-year Grant; Resulting Body of Work Will Inform Future Studies

The National Space Biomedical Research Institute's (NSBRI) Center for Acute Radiation Research (CARR) was tasked with assessing the acute effects of SPEs. The five-year grant for this center was awarded to the University of Pennsylvania School of Medicine in 2008 and is currently in its final year. A multidisciplinary team comprises the CARR and includes radiobiologists, physicists, physician scientists, and space life sciences students from the University of Illinois at Urbana-Champaign, the Armed Forces Radiobiology Research Institute, and the Massachusetts Institute of Technology.

CARR researchers focused on quantifying the risks related to SPE radiation exposure as well as developing and testing countermeasures to prevent and treat symptoms of acute radiation syndrome (ARS). Symptoms of ARS include prodromal symptoms, such as nausea, vomiting, and fatigue, and onset symptoms of ARS such as potential skin damage and immune system dysfunction.

Researchers used multiple model systems to identify biomarkers of disease prognosis and progression, to understand underlying mechanisms of injury, and to



CARR Investigators utilized the University of Pennsylvania Proton Facility for studies on the effects of SPEs (top photo). Special tools utilize magnetic resonance imaging (MRIs) to study how SPE dose distribution varies based on a person's unique physiology (bottom).

evaluate possible biological countermeasures for risk prevention and mitigation.

The culmination of this 5-year grant is a body of work with more than 40 peer-reviewed publications including results on the combined effects of microgravity and SPE radiation exposure on immune-system function. The completion of the CARR yielded important data quantifying the acute SPE effects that might compromise astronaut function and thereby affect mission success. This data will support updating of NASA's Acute Radiation Risk and Baryon Organ Dose model (ARRBOD).

Experiments at NASA Space Radiation Laboratory Log 1,300 Hours of Beam Time

The NASA Space Radiation Laboratory (NSRL) uses beams of high-energy heavy ions to simulate a typical space radiation environment plus SPEs, making it one of the few places in the world where investigators can conduct ground-based research in space radiobiology, shielding, and dosimetry. In addition to the state-of-the-art electron beam ion source, NSRL researchers also have the ability to simulate mixed space radiation fields in order to predict and mitigate risks to astronaut health from space radiation.

In FY2013, NASA researchers participated in three campaigns at the NSRL. During these campaigns, more than 100 experiments to irradiate a variety of biological specimens, tissues, and cells were conducted, with a total of about 1,300 hours of beam time. The results, published in numerous scientific journals such as *Proceedings of the National Academy of Sciences*, *Radiation Research*, and *PLOS ONE*, have supported the development of accurate models of radiation-associated health risks for carcinogenesis as well as research understanding degenerative tissue diseases and effects to the central nervous system.

In particular, animal data from heavy-ion cancer induction suggests a pattern of more aggressive and earlier appearing cancers associated with heavy particles relative to gamma-ray or proton exposures, in tissues such as the liver and colon. Additionally, an expanding body of evidence derived from ground-based research at the NSRL to simulate GCR using rodent models points to a potential risk for disruptions in cognitive performance and memory; these neurodegenerative effects may occur during relevant time scales for exploratory missions, and have the potential to produce a negative impact on mission success.

A researcher at the NSRL prepares biological samples (left) to be placed within the beamline (right). Facility upgrades made in FY12 and FY13 provide greater flexibility and speed in the ion source set-up.

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Overview

NASA uses the term "countermeasures" to describe the procedures, medications, devices, and other strategies that help 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. They provide 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.

Pre-flight countermeasures involve physical fitness and exercise and physiologic adaptation training. In-flight countermeasures include nutritional health, physical fitness, pharmaceuticals and sensory-motor training protocols. Post-flight countermeasures target rehabilitation strategies. Prior to flight testing, candidate countermeasures and technologies are developed and refined using ground-based studies.

The HHC is comprised of five portfolios that address physiological research, countermeasure validation and technology development. Major FY2013 accomplishments are reported in each portfolio's respective section: Vision and Cardiovascular, Exercise and Performance, Multi-System, Bone, 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

Long-Duration Crew Cardiovascular Study Completes Data Collection After 10 Years

The flight investigation "Cardiac Atrophy and Diastolic Dysfunction During and After Long Duration Spaceflight: Functional Consequences for Orthostatic Intolerance, Exercise Capacity, and Risk of Cardiac Arrhythmias," also known as Integrated Cardiovascular (ICV), was completed after nearly 10 years of experiment development and data collection. Principal investigators began data collection with their first subject in 2009 and collected data on 13 long-duration ISS crewmembers before the final crewmember returned on Soyuz 33 in May 2013.

ICV is the first comprehensive flight study to address alterations in cardiac structure and function, and how these changes affect the risk of cardiac rhythm problems. The intent of the study was to quantify the extent, time course, and clinical significance of cardiac atrophy associated with long-duration spaceflight. The study was also directed at identifying the mechanisms of this atrophy and the functional

A JSC scientist remotely guides an ISS crewmember through an echocardiographic examination of heart function.

consequences for crewmembers who spend extended periods of time in space.

Cardiac mass was measured before and after spaceflight using magnetic resonance imaging. High-resolution echocardiography (ECG) was used before, during and after spaceflight to assess cardiac structure and function, while at rest and exercising. Heart rhythm, blood pressure, and cardiac work were measured using high-fidelity, portable ECG monitors and continuous, ambulatory blood-pressure monitoring.

ICV data analyses are in progress, but preliminary results indicate that spaceflight-induced cardiac atrophy is related to the amount of exercise astronauts perform during missions. Those who exercised as much as, or more than, they did before their mission seem to have maintained or increased cardiac mass. It also appears that the incidence of cardiac rhythm abnormalities does not increase during or after spaceflight. The entire dataset will be examined thoroughly and the results will be published in relevant journals and presented at scientific meetings.

ISS Ocular Health Study Addresses Primary Human Spaceflight Risk

The "visual impairment and intracranial pressure" (VIIP) syndrome is currently NASA's foremost human spaceflight risk. Microgravity exposure has been linked with worsening near visual acuity in crewmembers, changes in ocular structure, and in some cases increased intracranial pressure (ICP) when they return to Earth. Although the eye seems to be the main organ affected by this syndrome, the ocular effects are thought to be related to changes in the vascular system and the central nervous system.

Scientists believe that microgravity-induced headward fluid shifts, coupled with a loss of gravity-assisted drainage of venous blood from the brain, lead to fluid congestion in the head and increased ICP. Elevated ICP is thought to induce structural changes in the eye that, over time, result in visual impairment. Prolonged elevation of ICP can cause long-term reduced visual acuity and peripheral vision. It has also been reported to cause mild cognitive impairment in patients having idiopathic intracranial hypertension—the clinical population on Earth that is most similar to the affected astronaut population. The health consequences associated with these conditions are potentially irreversible.

To better understand the timing and contributing risk factors of the VIIP syndrome, the Ocular Health experiment expands on the medical testing that each ISS crewmember undergoes. The study will define the time-course for the appearance of signs and symptoms; help scientists understand the interaction between duration of weightlessness and severity of symptoms; establish preflight baseline characteristics; determine the nature of in-flight changes; document changes from pre- to postflight; record the postflight

As part of the Ocular Health Study, a crewmember has his eye imaged using Optical Coherence Tomography (OCT).

time-course for recovery to baseline; and determine the impact of prolonged changes on crew health.

Pre- and postflight evaluations include visual testing, exams to assess the health of the eye, intraocular pressure, cardiovascular compliance, noninvasive intracranial pressure and brain imaging. In-flight evaluations include visual testing, ocular imaging and ocular pressure measurements, cardiovascular compliance, and transcranial Doppler testing.

Data from this study will guide countermeasure development and target treatments for preventing the VIIP syndrome and its complications. To date, scientists have recruited seven crewmembers out of an anticipated total of twelve subjects. Preflight data collection has been completed on six of the participants, and in-flight data collection has been completed on two and is underway for a third crewmember.

EXERCISE AND PERFORMANCE PORTFOLIO

ISS Treadmill Exercise Study Demonstrates Benefits of Fast Running

Treadmill exercise is an important component of the exercise countermeasures astronauts use to maintain muscle, bone mass, and cardiovascular health. ISS crewmembers have used treadmill exercise since Expedition 1 in 2000. The treadmill on the ISS is much like one found in gyms on Earth, but it has a few important differences. First, it is instrumented so that ground-reaction forces can be measured with each step. Second, astronauts must wear a harness, tethered to the treadmill with bungees, so that they don't float away with every footfall. It has long been assumed that the harness pull-down load is the most important factor influencing the ground-reaction force. However, it is difficult for astronauts to run when the harness is loaded at a full body weight.

The Treadmill Kinematics study was completed in 2013 with the objective to evaluate the ground-reaction forces obtained while treadmill users ran at various speeds and with various harness loads. Astronauts typically prefer a harness load of only 63% of their body weight for the most comfort while running. Their joint motions, and therefore running gait patterns at 0g and 1g, were highly consistent. This suggests that astronauts adapt to weightlessness and that complex multi-joint movements requiring balance in normal gravity can be maintained despite altered neural input from the vestibular system.

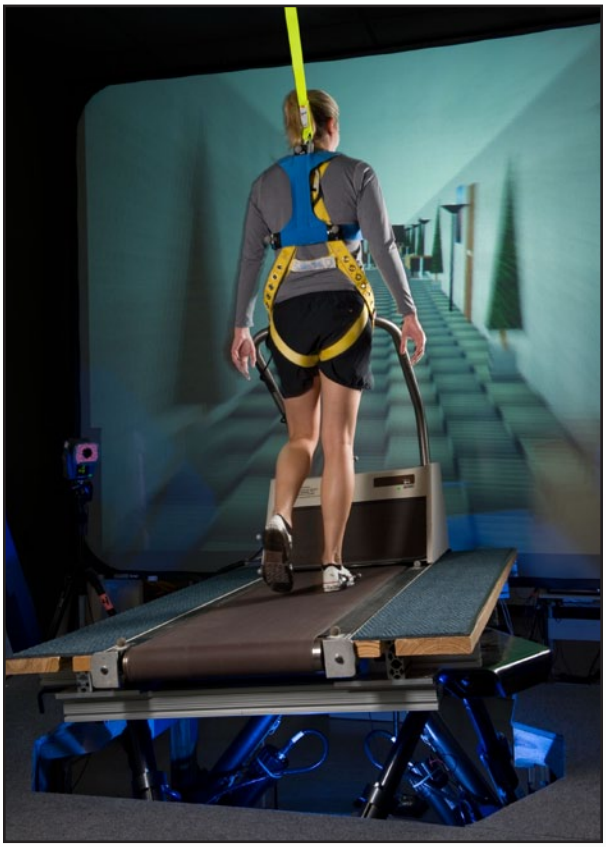
Running in space requires subjects to be harnessed and tethered with bungees. The Treadmill Kinematics study highlighted the need for faster running to achieve the same foot-force as a subject walking on Earth.

Data indicated that typical foot forces at a given speed in space are less than those occurring at the same speed in normal gravity because the harness loads were less than full body weight. However, foot force increased with faster speeds, and importantly, the ground-reaction force associated with fast running in space was similar to the ground-reaction force associated with walking on Earth. Astronauts were able to run faster in space than on Earth and

this study demonstrated the benefits of including fast running in future exercise programs.

Development of Countermeasures to Enhance Sensorimotor Adaptation

When astronauts return to Earth, they experience balance and gait disturbances as they re-adapt to moving in an environment with gravity. These disturbances may disrupt astronauts' ability to perform critical tasks if they were to land on a planetary surface after prolonged exposure to 0g. To mitigate this risk, NSBRI researchers developed a comprehensive sensorimotor adaptability (SA) training program to enable rapid adjustment from microgravity to a partial- or full-gravity environment, such as would occur during a landing on Mars.



A subject walks on a tilting treadmill while presented with a virtual-reality, moving scene. Exercises like this are thought to improve balance adaptability and could be used as a countermeasure for astronauts returning from space.

The study's objective was to develop a training program to enhance the brain's ability to adapt to new gravity environments—a process called "learn to learn." A unique training system was developed that was composed of a treadmill mounted on a motion base, which produced movement of the treadmill's support surface during walking. This movement provided challenges to balance and gait stability. Additional sensory challenge was provided by having the subject view a large, projected virtual scene that exposed them to conflicting visual motion during treadmill walking. Subjects trained while being exposed to different combinations of support-surface movement and visual-scene motion that allowed them to improve their ability to adapt while experiencing challenging and conflicting sensory information.

The research team demonstrated that adaptation to walking in a discordant sensory environment has a significant effect on locomotor stability, reaction time, and metabolic cost. These results suggest that SA training improves performance during balance disturbances associated with spaceflight. SA training programs also have significant terrestrial applications for rehabilitating patients with balance disorders and for preventing senior citizens from falling.

MULTISYSTEM PORTFOLIO

Study Shows Increase In Iron Stores Related to Oxidative Damage and Bone Loss

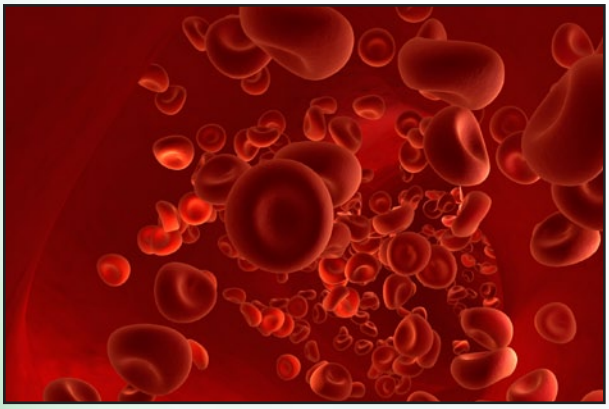
A recent publication from the Nutrition Supplemental Medical Objective (SMO) study indicates that iron stores increase early during spaceflight, and then return to preflight concentrations by the end of a 6-month mission. The key finding from this study is that the increase in iron stores during flight is related to both oxidative damage and bone loss.

Iron stores increase in microgravity because blood volume decreases during the initial weeks of spaceflight. The iron in excess red blood cells (RBCs) is

not reused by new RBCs during spaceflight and is stored in tissues. This increase in iron stores was associated with increased indices of oxidative damage, and furthermore, the magnitude of the increase in iron stores during flight was correlated with loss of bone mineral density. That is, the greater the iron stores during flight, the more bone loss was observed after flight. As with many nutrients, although not getting enough iron is a common concern, getting too much is also cause for concern.

This study, along with other recent papers from non-NASA laboratories, shows that increased iron stores can be problematic, and that these effects are seen at well below what are typically considered toxic levels of iron. In the broader context, this paper points out that research on the ISS has implications far beyond NASA for the general medical and scientific communities, and the general population.

With regard to spaceflight, further research is required to better understand changes in iron metabolism in astronauts on long-duration missions, and how these changes are related to other health concerns of space travel, including radiation, cancer risk, and immune dysfunction. The health effects of iron have significant implications for the spaceflight food system, which provides about three times as much iron intake as the Earth-based recommended dietary allowance calls for. On missions to other planets or celestial bodies, this could cause or contribute to significant health issues.

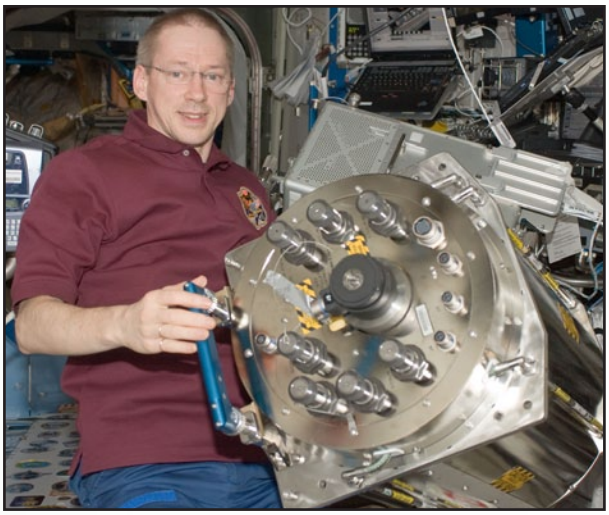


The iron in excess red blood cells (RBCs) is not reused by new RBCs during spaceflight and is stored in tissues causing an increase in overall iron stores which can lead to toxic effects.

ISS Operational Research: Urinary Calcium and Optimum Water Recovery Rate

The ability to reclaim water from urine offers the possibility of substantial cost savings for future exploration-class missions. To meet this need, a prototype ISS Urine Processor Assembly (UPA) was developed to process urine into water and strived to achieve an 85% reclamation goal. In 2009, the UPA was clogged by an unknown substance and data from the Nutrition SMO was leveraged to help address the issue.

The Nutrition SMO data showed overall urine volume was about 17% lower during flight, but urinary calcium concentration was 50% greater during flight than before flight. Calcium was found to be a major component of the substance clogging the UPA, and the increased urinary calcium concentration during flight was identified as a primary reason for the UPA failure. New recommendations to reduce water recovery to 70% were made in 2010 as a result of those findings.

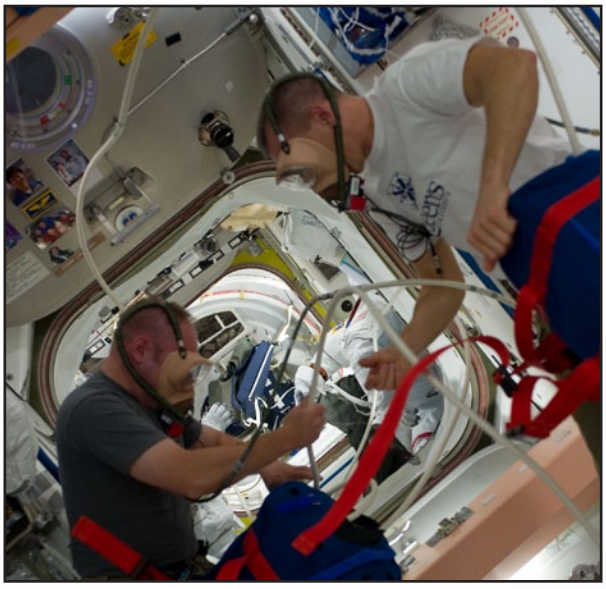


An ISS crewmember works with the clogged Urine Processor Assembly in 2009. Data from the Nutrition SMO study provided insight leading to the discovery that urinary calcium was the major component of the malfunction.

In 2012, when the data was re-evaluated with an additional ten subjects, it was evident that crewmembers had consumed more fluid than in the past, and as a result, urinary calcium concentration was lower. After reviewing the data, ISS Program managers opted to increase water recovery from 70% to 74-75%. This will save an estimated 80 liters of water per year, and 6-7 hours of crew time needed to change tanks. This recovery rate will also delay by several months the point where water will need to be launched to the ISS. The cost savings resulting from these recommendations will be significant.

Proven Prebreathe Protocol Now Included as DCS Standard in NASA-STD-3001

During a content review of the NASA Human Spaceflight Standards, members of the extravehicular activity (EVA) discipline highlighted the need to include a new standard pertaining to the acceptable risk of decompression sickness (DCS). DCS prevention requires the elimination of nitrogen (N_2) gas from body tissues saturated to a normal sea-level environment and is crucial for crew safety.



Crewmembers prebreathe 100% oxygen via a mask prior to entering the airlock and donning their space suit. This prebreathe reduces the nitrogen content in the tissues and reduces the risk of decompression sickness during their EVA.

Before transitioning to a significantly lower EVA suit pressure, astronauts prebreathe 100% oxygen to displace the N_2 in the tissues. This prebreathe prevents the formation of N_2 gas bubbles that can come out of solution and cause localized joint pain or severe cardiopulmonary or neurologic symptoms in the worst cases. Although necessary, the time spent prebreathing oxygen can be lengthy, so in 1997 the DCS Acceptable Risk and Contingency Definition Plan was initiated with a mix of internal NASA and external scientific personnel.

This effort defined the acceptable risk of DCS necessary for the safe assembly of the ISS. It established that any approved prebreathe protocol to be used on the ISS must be tested in a pressure chamber on the ground and have a DCS incidence of no more than 15% at a 95% confidence level. Additionally, it must cause no cardiopulmonary or central neurologic symptoms and the rate of severe venous gas emboli should be less than 20%.

Research efforts followed to develop three new prebreathe countermeasures for DCS, all significantly reducing preparation time and preventing DCS during EVA. Although this level of acceptable risk was originally chosen to ensure the safe construction of the ISS, fifteen years of successful use indicated it might be the correct risk level for the NASA-STD-3001 Volume 1, Crew Health Standards. The recommended risk limit was accepted for inclusion in the updated standard.

NASA Bone Summit Review Published in the *Journal of Bone and Mineral Research*

With the completion of the ISS, NASA has conducted medical assessment tests for bone health in 33 astronauts over the course of ten years. As in terrestrial medicine, NASA evaluates bone health by the measurement of bone mineral density (BMD) using dual-energy x-ray absorptiometry (DXA). DXA is often used to identify people with higher fracture risk and diagnose osteoporosis, a skeletal condition

that may not manifest in a crewmember until 15 or more years after a mission. However, because of the small numbers of ISS astronauts, NASA does not have the level of evidence typically required in terrestrial medicine to develop clinical practice guidelines.

In 2010, a Bone Summit Panel, composed of clinical experts and policymakers in the field of osteoporosis was convened. They reviewed all the data accumulated with respect to ISS astronauts to determine if NASA was using the optimum tests to understand spaceflight-induced bone loss. The data included BMD, hormone levels, urine and blood biomarkers that reflect bone breakdown and bone formation, measures of in-flight exercise activity, as well as family and personal medical history.

The Bone Summit panel recommended both clinically-accepted tests and innovative research directions to counterbalance the unique constraints and issues of risk management in astronauts. The panel's interpretation of and recommendations for biomedical data were published in the June 2013 edition of the *Journal of Bone & Mineral Research* as an invited review paper.

Recommendations of the Bone Summit Panel were featured in an article, 'Skeletal Health in Astronauts', published in the June 2013 issue of Journal of Bone and Mineral Research.

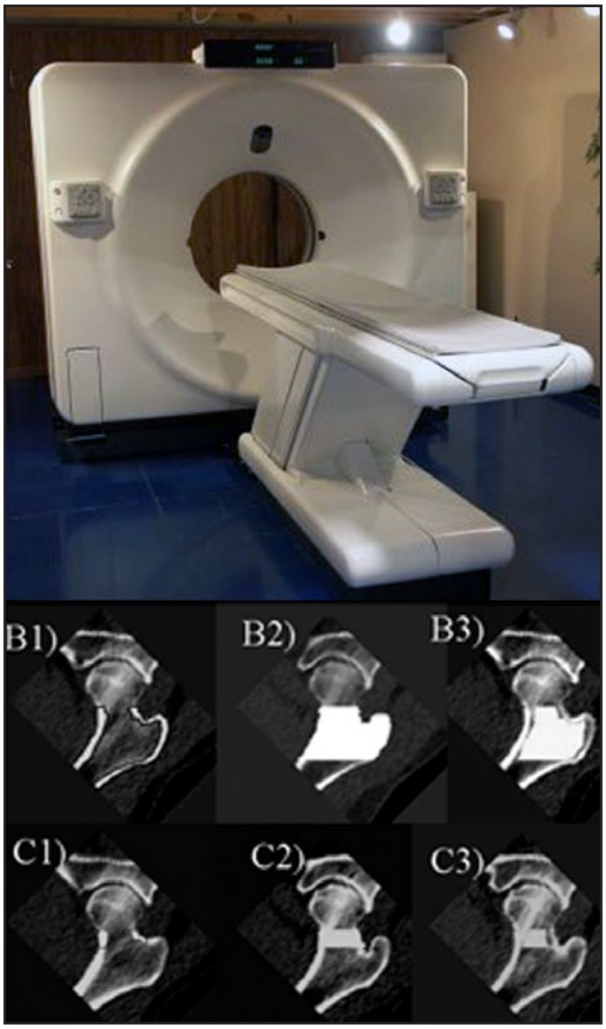
Bisphosphonates and Exercise to Protect Bone During Long-duration Space Flight

Skeletal health on Earth is maintained by a carefully regulated turnover, or remodeling, of bones. However, data used to describe the effects of spaceflight on astronauts' bones, suggest that bone remodeling in space is disrupted—with bone removal exceeding bone replacement. This unbalance could result in a net loss in bone mass and may lead to osteoporosis, bone fractures, or even renal stones in astronauts.

Patients on Earth diagnosed with osteoporosis can be treated with bisphosphonates, a class of drugs that prevent the loss of bone mass. An ISS flight study is testing a bisphosphonate, called alendronate, to suppress bone breakdown during spaceflight. It is hypothesized that the combination of alendronate with exercise would prevent bone breakdown better than exercise alone. Data describing the skeletal response to bisphosphonates and exercise in space have recently been published in the Volume 24, July 2013 edition of *Osteoporosis International*.

ARED exercise is a proven countermeasure against bone loss. The bisphosphonates study suggests a combination of drug treatment and exercise as the optimal countermeasure.

Previous spaceflight studies show that resistive exercise with ISS exercise equipment, such as the Advanced Resistive Exercise Device (ARED), significantly reduces the average decline in BMD. Adding an oral alendronate treatment to ARED exercise reduces the average decline even further as well as reducing the loss of calcium in the urine. Some results also showed increased bone mass in the lower back, which while encouraging, cannot be attributed solely to the contribution of the drug treatment as opposed to the influence of exercise, especially on bone structure.



A high-resolution QCT scanner (top) is used to evaluate the changes in bone mineral density of both trabecular and integral bone compartments of the hip. These measurements are used to assess the effect of bisphosphonates to prevent the loss of bone mineral in ISS astronauts.

Going forward, the bisphosphonate flight study has been extended to include ten "control" astronauts who will exercise on ARED, but not take the bisphosphonate. The addition of untreated astronauts will facilitate the assessment of changes in hip bone structure when compared to the experimental group. Subjects will be scanned by quantitative computed tomography (QCT)—a technology that allows for more detailed imagery. These additional QCT measurements will enable a comparison of bone structural data from the new control group to the recently published QCT data from the experimental group.

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Overview

Human exploration of the Moon, Mars, and other destinations beyond Earth orbit will present significant new challenges to crew health. During exploration missions, the crew 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 protect patients' private medical data. These data systems also aid in the diagnosis of medical conditions, and act as repositories of information about relevant NASA life science experiments.

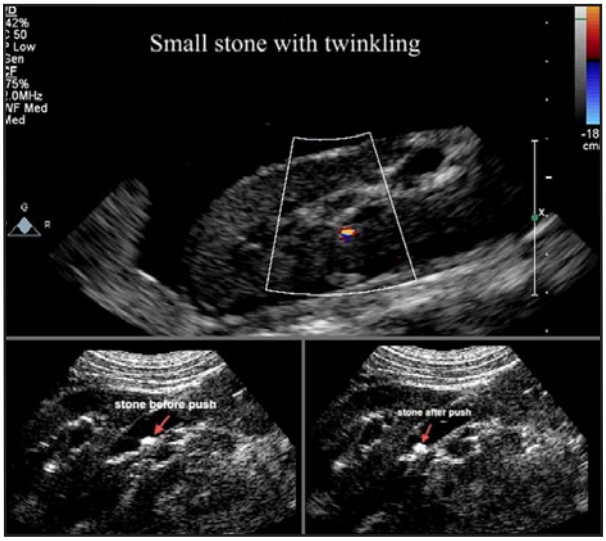
ExMC physicians and scientists develop models to quantify the probability of medical events occurring during a mission. They also define procedures to treat an ill or injured crewmember without access to an emergency room and with limited communications with ground-based personnel for consultation and diagnostic assistance. To read more about the Exploration Medical Capability Element, please visit: http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-exmc.html.

New Technology to Diagnose and Treat Kidney Stones During Spaceflight

National Space Biomedical Research Institute (NSBRI) Investigators developed an ultrasound-based device designed to reduce kidney stones to a safe size and treat various medical conditions during long-duration spaceflight. This new technology is capable of detecting kidney stones with advanced ultrasound imaging, based on a process called "twinkling artifact," and provides treatment by moving the stone using high-intensity focused ultrasound (HIFU). The device is intended for use by non-physicians during spaceflight and on Earth, and will help mitigate some of the treatment challenges associated with kidney stones.

The risk of developing kidney stones is increased during spaceflight as a result of the microgravity environment and the difficulty of keeping astronauts fully hydrated. Bones demineralize in the reduced-gravity environment of space, dumping salts into the blood and eventually into the urinary system. This elevated concentration of salts in the urine increases the risk of developing kidney stones.

The ability to treat a patient who develops a kidney stone during spaceflight is limited by the resources available. This new technology is intended to provide an on-orbit diagnostic and therapeutic system that



The "Twinkling" method of detection (top) and repositioning of kidney stones (bottom) helps to pass stones by using high-intensity focused ultrasound energy at diagnostic levels.

non-physician crewmembers can use in the diagnosis and treatment of kidney stones.

The ultrasound technology could also change the treatment of kidney stones on Earth. Many kidney stones do not resolve with hydration and more aggressive approaches are often required. Patients with painful kidney stones must be treated multiple times before the stones are entirely cleared.

This novel treatment approach can enable the clearance of a kidney stone during the first office visit and can be used to stop internal bleeding, destroy tumors and clear an obstruction of the urinary tract caused by a stone. The control of bleeding with HIFU ultrasound has significant potential to save lives in both civilian and military contexts. A "first-in-man" clinical trial utilizing HIFU to move kidney stones, co-sponsored by NSBRI, is currently underway at the University of Washington School of Medicine.

New SCAN Technology for Bone Quality Assessment and Fracture Healing

Astronauts on long-duration spaceflights are theoretically more susceptible to fractures because they

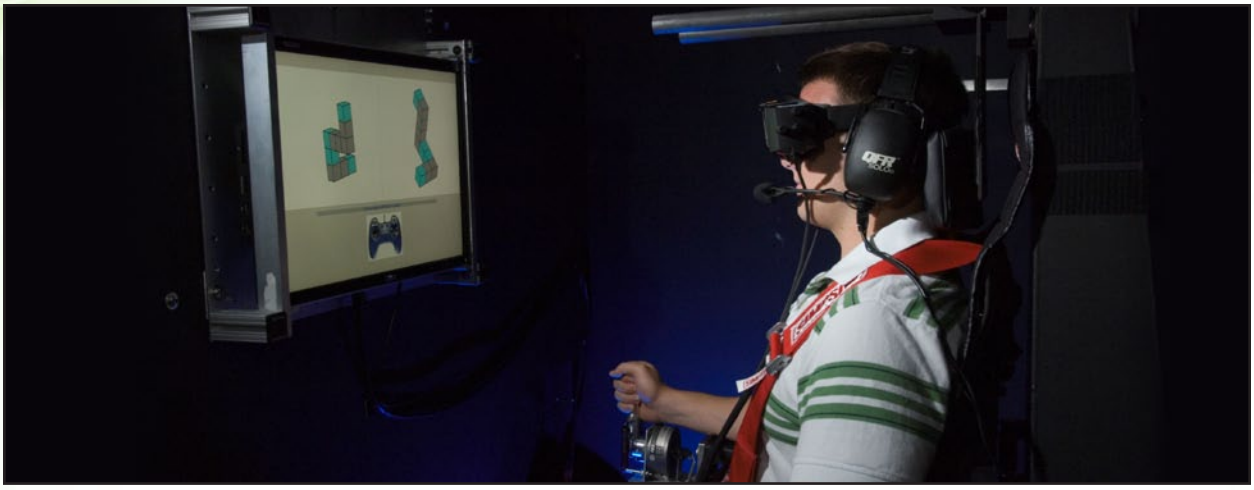
Investigators prepare to use the SCAN device to produce an ultrasound image. This new technology allows early prediction of bone disorders and acceleration of fracture healing.

lose bone strength and structure. Early detection and treatment of bone loss will be very useful for preventing fractures. The current measurement method, X-ray absorptiometry, is limited in its ability to provide a complete picture of bone health. New ultrasound technology developed by NSBRI investigators, known as scanning confocal acoustic navigation (SCAN), has shown potential for providing measurements of bone structure and strength, and guiding effective treatment. It also offers the possibility of accelerating the healing of fractures.

NSBRI investigators have developed an ultrasound technology for combined diagnosis, treatment, and early prediction of bone disorders and guided acceleration of fracture healing, using SCAN imaging and low-intensity pulsed ultrasound. This research study has determined the relationships between ultrasonic parameters and bone density and bone's physical properties, such as stiffness and modulus. The SCAN

device, when combined with a therapeutic system, can generate acoustic images at the regions of interest for identifying the strength of trabecular bone. The system has a resolution and sensitivity comparable to those of existing technologies and has been successfully used for imaging bed rest subjects and clinical tests of bone integrity.

This research also has important terrestrial applications, as osteoporosis and the delayed healing of fractures are major health problems on Earth, particularly in post-menopausal women. Early diagnosis that can predict fracture risk and result in prompt treatment, can have a high impact with respect to improving the health of aging populations on Earth.



Overview

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

The SHFE portfolio establishes human factors standards and guidelines for interaction of the human system with hardware, software, procedures, and the spacecraft environment. SHFE provides validated human models for predicting the effects of interface designs on human performance, methods for measuring performance of humans and the human-system combination, and improved design concepts for advanced crew interfaces and habitability systems. SHFE also facilitates development of tools, metrics, and methodologies for use in implementation, assessment, and validation of standards and requirements.

The AEH portfolio focuses on understanding the risk of microbial contamination of spacecraft and on the establishment of permissible exposure limits to potential toxins such as lunar dust. The AEH portfolio also proposes countermeasures to these risks and makes recommendations relating 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 in exploration missions, while investigating processing methods to extend the shelf life of food items up to five years. The portfolio also delivers improvements in both the food itself and the technologies for storing and preparing it.

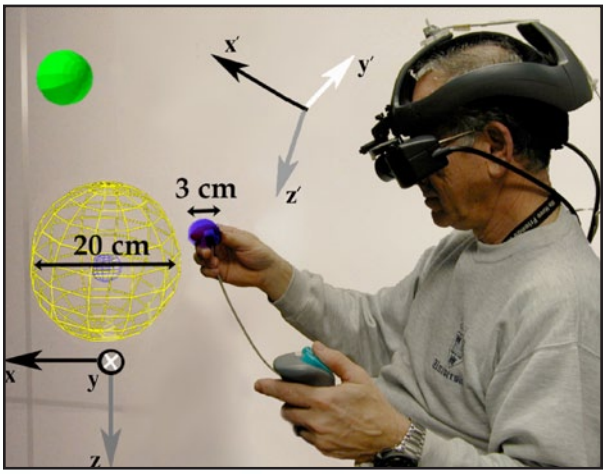
To learn more about SHFH, please visit the public website at: http://www.nasa.gov/exploration/humanresearch/elements/research_info_element-shfh.html

SPACE HUMAN FACTORS ENGINEERING PORTFOLIO

Insight Into Operator Task Performance Associated With Transmission Delays

ISS crew conduct teleoperations as they control the large robotic arm to maneuver portions of the space station, to capture and berth new supply vehicles, and to move astronauts as they conduct spacewalks. As humans venture farther away from the systems they are remotely manipulating, communication delays will increase.

Small delays are typically encountered during local transmissions, for example, when an astronaut controls a robot that is located within line of sight. Greater transmission delays occur when the distance between the controller and the robot increases.



A subject wears a virtual-reality headset which displays several computer-generated objects. The task is to move a ball (purple) into position to touch a larger target (green) while compensating for simulated transmission delays.

The implications for teleoperations are significant—even small delays, on the order of a few hundred milliseconds, will cause operators to adopt what has been called a "move-and-wait" behavior. Even longer delays will necessitate reliance and monitoring on non-interactive automated systems.

Researchers are interested in analyzing the human performance effects when transmission delays change from near-zero to 800 milliseconds. NASA's Ames Research Center conducted three experiments to study the influence of latency on manual performance using a virtual telerobot, as a function of task difficulty. Teleoperations were simulated in a virtual environment where participants were asked to move a computer-generated sphere by reaching to a target in three-dimensional space.

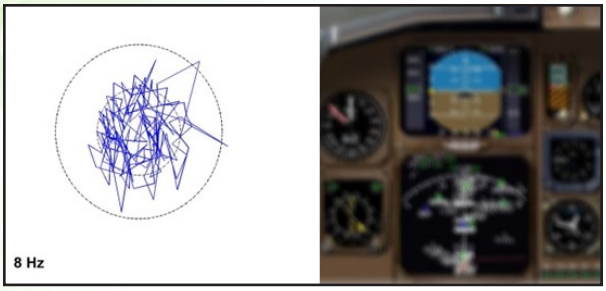
Study results suggest the complexity of the reaching maneuver and the length of the delay affect task performance efficiency and accuracy. The results also revealed some interesting operator behaviors to be modeled in future studies. Further research will also determine how this new knowledge can be applied to improve existing techniques which lessen the effects of communication latencies in teleoperations.

Designing Human-System Interfaces for Spaceflight Environments

In space, astronauts operate in the relative calm of microgravity. However, the trip to and from space is not a smooth, easy ride because of extreme vibrations and gravity levels that could reach as much as four times that of Earth's gravity. These conditions can limit the ability of crewmembers to perform their jobs successfully. The next generation of human spaceflight vehicles will expose astronauts to vibration levels much higher than those experienced during the Space Shuttle Program, and may hamper their ability to perform critical tasks such as override of automation in emergencies. This combination of a high-gravity plus a high-vibration environment is known to interfere with certain neurological functions involving the senses and muscle movement, and is thus a significant risk to crewmembers' sensorimotor performance.

An NSBRI study measured human performance of navigation and flight-control tasks during periods of high vibration and altered gravity, similar to the environment expected to occur in NASA's new Orion vehicle, as well as in commercial space vehicles. The researchers used the data collected to develop a computer model of human performance during the two tasks.

Their results indicated that stabilization of gaze while a person is performing a task, which occurs through the action of the vestibulo-ocular reflex, is not the limiting factor for sensorimotor control while crewmembers are experiencing sustained gravity loads and vibration. The research team found that both vibration and increased gravitational loading can significantly increase systematic physical errors. One type of error is in making saccades, which are rapid eye movements changing the direction of gaze, and another error is in using the hands to reach objects such as controls. This study also showed that elevated gravitational loads and vibration generated changes in the function of the autonomic nervous



A measure of eye movements or 'gaze position' under 8-Hz of vibration (left). A blurred cockpit display as a subject might perceive while under vibration (right) which shows the visual significance caused by the failure to maintain gaze stability.

system (ANS) that were consistent with increased workload, showing that ANS effects are linked to task performance.

These results have enabled human capabilities and limitations to be identified and modeled, to provide guidelines for designing displays and controls. The knowledge gaps filled by the above findings will enable the development of sensorimotor performance models and improved guidelines for design of interfaces, such as controls, between humans and spacecraft systems. These models and guidelines will ultimately reduce mission risk and improve safety.

ADVANCED ENVIRONMENTAL HEALTH PORTFOLIO

Expert Panel Develops Next-Generation Spaceflight Microbiological Requirements

To decrease the chance of microbial contamination and possible crew infection during spaceflight missions, microbiological requirements are established for spaceflight vehicle design and operations. The effectiveness of these requirements is verified by microbiological monitoring, which can occur before launch or during flight. As technology advances and lessons are learned on current missions, microbiological requirements are reviewed to appropriately optimize the use of valuable spaceflight resources, such as crew time, while retaining the goal to protect crew health.

An ISS crewmember collects a potable water sample which will be tested for contaminates. An expert panel recommended using advanced technologies such as DNA detection to enable more in-flight testing.

To refine current and future microbiological requirements, the AEH Portfolio convened a series of three forums, consisting of internal and external subject matter experts. These panels reviewed current requirements, historical data, and plans for future spaceflight missions. Included in these discussions were recent advances in monitoring and analysis technology that could provide better information during a spaceflight mission.

Each forum focused on specific routes of microbial contamination, specifically potable water, vehicle air and surfaces, and spaceflight food. Several common themes were observed in the recommendations from each panel. For example, all panels agreed that technology for analysis and processing will need to advance to enable in-flight microbiological monitoring especially as missions leave low Earth orbit. Current methods used on the ISS, such as surface

swabbing and subsequent growth of microorganisms on media plates, will need to be replaced with alternative monitoring technologies. Newer DNA-based detection methods could lead to smaller, more efficient spaceflight hardware. The interim report recommendations also included novel vehicle system concepts and changes to mission operations. A final report on the cumulative recommendations for all sample types will be delivered in December 2014.

ADVANCED FOOD TECHNOLOGY PORTFOLIO

AFT Researchers Offer Meal Replacement Foods to Help Reduce Spacecraft Mass

Long-duration space missions beyond low Earth orbit require mission planners to balance the provisioning of a safe, palatable, and nutritious food system with the use of limited resources such as water, crew time, volume, mass, and power. Although meal replacement foods are commercially available that could reduce the mass of the food system, they do not meet the nutritional requirements for spaceflight. Advanced Food Technology (AFT) researchers were tasked with identifying technologies to formulate nutrient-dense meal replacement options that meet the requirements of long-duration spaceflight.

Meal replacement bar and beverage prototypes were developed to meet macronutrient requirements for breakfast and lunch meals. Additionally, researchers identified nutrient-dense commercial foods or developed new prototype formulations to periodically replace some low-nutrient-density soups and desserts.

Accelerated shelf-life testing was also conducted and had an average stability range of 48 to 96 weeks. Bars had a 48- to 72-week shelf life, whereas beverages and most nutrient-dense product replacements remained stable for 96 weeks. AFT researchers made recommendations to improve shelf life and include micronutrients in future iterations of development.

Test bars at the end of accelerated shelf life testing of 48 to 72 weeks: (clockwise from top left) Chocolate Peanut Butter Bar, Peanut Butter Sandwich Bar, Dark Chocolate Mini Loaf , and Pumpkin Mini Loaf .

A variety of menus were proposed that implemented bar and beverage substitutions in the standard ISS menu. Estimates indicated that replacing a meal every day could result in a reduction of food mass ranging from 11-25%, but psychological and acceptability impacts of extensive substitution need to be considered. Additionally, the current food system contributes 500 ml of water per day, per crewmember. Nutrient-dense meal replacements have a reduced water content, which may affect the savings of total mass on missions where water is not recycled.

Nutrition and Prototype Delivery System for Extended Suited Contingency Operations

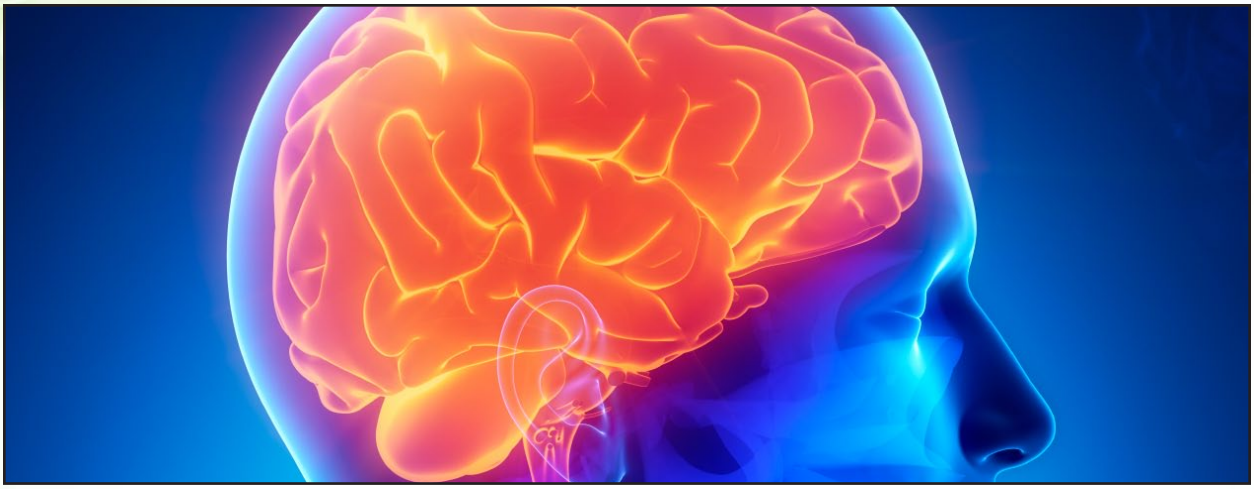
The contingency scenario for an emergency cabin depressurization event onboard the Multi-Purpose Crew Vehicle (MPCV) may require crewmembers to wear a pressurized suit for up to 144 hours. While suited, crewmembers require sufficient nutrition to maintain strength and cognition to perform critical tasks. This contingency scenario requires the capability for safe nutrition delivery through a helmet feed port against a 4-psi pressure differential.

To address this scenario, researchers developed and analyzed two nutritional delivery prototypes for compatibility with the helmet feed port interface and for operational effectiveness against the pressure differential. A 'bag-in-bag' prototype, designed to equalize the suit pressure with the beverage pouch

Current pressurized suits do not have a feed port to facilitate drinking while fully suited. Future suits will feature a feed port in the helmet which would allow the delivery of nutrition to sustain a astronaut during emergency situations lasting up to 144 hours.

and enable a crewmember to drink normally, delivered water successfully to three different subjects in suits pressurized to 4 psi. A second 'boa restrainer pouch' prototype was designed using mechanical leverage to overcome the pressure differential but did not operate sufficiently.

Guidelines were also developed and compiled for contingency beverages that provide macro-nutritional requirements, a minimum one-year shelf life, and compatibility with the delivery hardware. The evaluation results and food product parameters of this research study will help to improve future prototype designs and develop sufficient nutritional beverages for contingency events. These nutrition capabilities would have additional use in extended EVAs during surface missions, where the current in-suit drinking device may be insufficient.



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 also lead to neurobehavioral 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 areas: Behavioral Medicine Risk, Team Risk, and Sleep Risk. The Behavioral Medicine Risk area works to develop self-assessment tools for early detection and treatment that use unobtrusive and objective measures of mood, cognitive function, and other behavioral reactions to living and working in space. The Team Risk area examines team performance and other team-related outcomes, including crew cohesion and communication, to develop tools and technologies that monitor and support teams throughout autonomous operations. The Sleep Risk area focuses on countermeasure development, including lighting protocols, medication recommendations, education, and tools that optimize work-rest schedules.

The end result is to provide technologies and tools that will optimize the adaptation of the individual and crew to the space environment, and maintain motivation, cohesion, communication, morale, well-being, and productivity.

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

Fatigue Management for ISS Mission Flight Controllers Working Overnight Shifts

Spaceflight operations on the ISS depend on the support of the Mission Control Center (MCC) at the NASA Johnson Space Center. It is essential that flight controllers working shifts in the MCC remain

The Experimental Break Room inside the Johnson Space Center's Mission Control Center.

alert and maintain high levels of mental function while operating and monitoring complex, technical equipment. When they support missions, flight controllers are often required to adapt to working overnight shifts in MCC. This change in schedule is commonly associated with fatigue caused by acute and chronic sleep deprivation and misalignment of daily rhythms.

In a recent BHP study, investigators from Brigham and Women's Hospital and Harvard Medical Center evaluated the feasibility, acceptability, and efficacy of ways to counteract fatigue in flight controllers. They addressed the feasibility of creating an experimental break room (EBR) outfitted with blue-enriched light and exercise equipment, and the acceptability of scheduling flight controllers for two 20-minute breaks to use the EBR during overnight shifts. They then tested the efficacy of the EBR by comparing the alertness and performance of flight controllers during overnight shifts when they had access to the EBR to the alertness and performance of those same controllers during overnight shifts when they did not have access to the EBR.

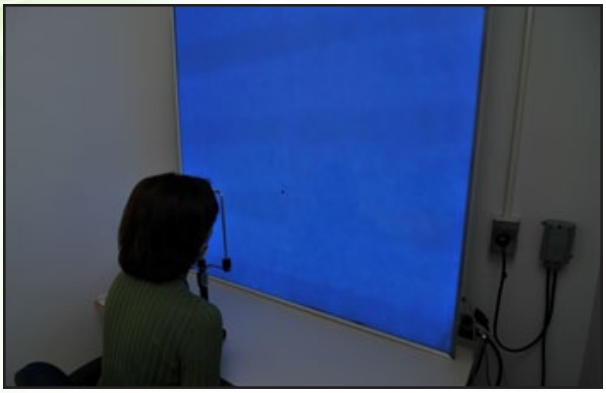
Each of the twenty participants was scheduled to work two 4- to 7-day blocks of night shifts during the study, one in the experimental condition and one in the control condition. During the experimental condition, controllers were encouraged to visit the EBR before, twice during, and then after their shift so they could make use of the blue-enriched light and the treadmills or stationary bikes. The flight controllers in the control condition were instructed to continue their normal routines.

Flight controllers completed brief rating scales to self-assess their alertness levels, and a 5-minute Psychomotor Vigilance Test that objectively measured their vigilance. They also wore actigraphs to monitor their sleep. Preliminary results indicate that the fatigue countermeasures were effective at helping flight controllers remain alert during their shifts, and BHP researchers will inform Mission Operations about ways to improve the alertness, performance, and safety of controllers working overnight shifts.

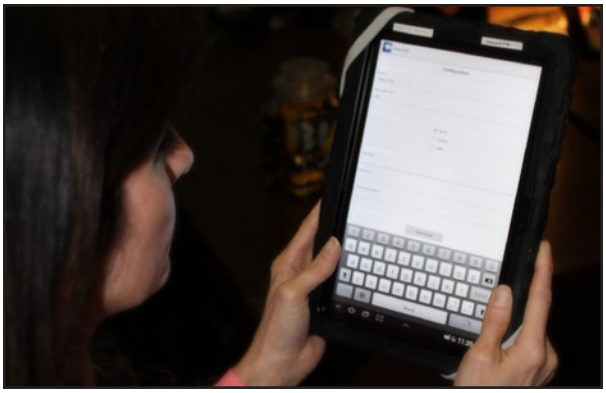
Optimized Lighting Improves Astronaut Performance for Long-Duration Exploration

During ISS spaceflight missions, sleep deficits constitute a serious risk factor. These deficits can diminish alertness levels, mental abilities, and psychomotor performance. Disrupted sleep patterns can result in decreased vigilance and concentration and can compromise the performance and safety of both astronauts and NASA ground control workers. Previous research studies have shown that treatment with certain types of light can correct similar impairments that occur as a result of shift work, jet lag, and sleep disorders. To help lessen this risk, an investigator with the National Space Biomedical Research Institute (NSBRI) has shown that blue-enriched fluorescent light can be used as a countermeasure to regulate the daily sleep-wake cycle, or circadian rhythm, at the low lighting levels common in spacecraft.

In this research effort, investigators developed a high-fidelity replica of the ISS crew quarters as an analog environment for testing the acute neuroendocrine responses to light stimuli. The analog facility was equipped with the ISS prototype lamps to accurately copy current and proposed lighting countermeasures, and to demonstrate the feasibility of using blue-enriched fluorescent light for regulat-



A study subject undergoes exposure to monochromatic blue light. Optimized lighting during spaceflight can improve the sleep and biological rhythms of astronauts.



BHP personnel use the Behavior Tracking Software System to capture real time feedback during testing sessions.

ing circadian rhythm. These studies provided data on visual sensitivity, melatonin secretion, alertness, neurobehavioral responses, and sleep parameters. They also provided data on how effective the white light from the ISS lamps was as a countermeasure to regulate circadian rhythm. Additionally, the results have shown that dim, long-wavelength polychromatic illumination with a color-correlated temperature of 2,300 Kelvin impairs the ability to distinguish one color from another, or color discrimination.

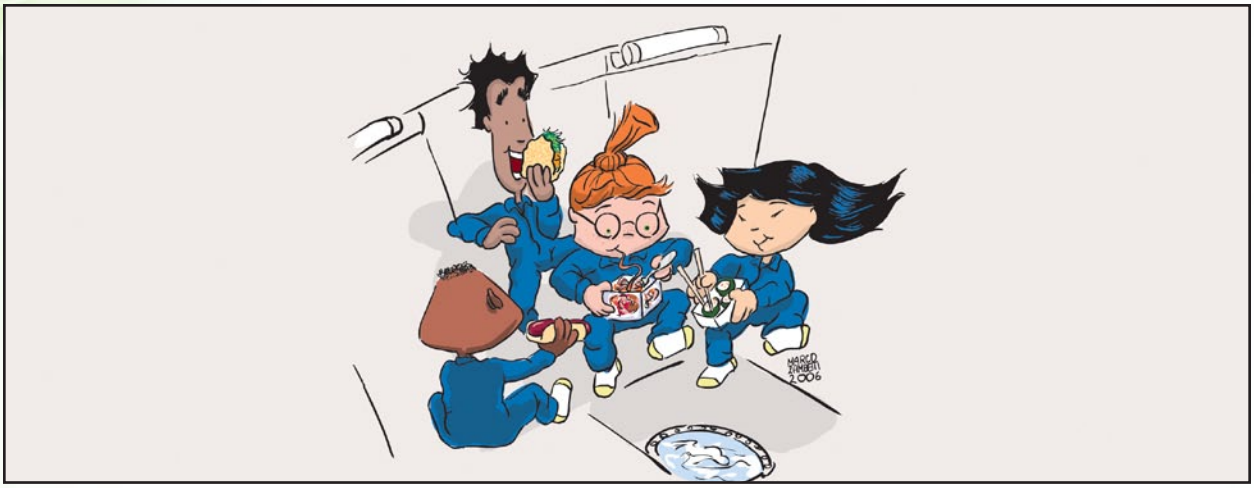
Onboard artificial lighting systems can serve the dual purpose of maintaining day-to-day circadian rhythms while providing illumination that supports vision. The results from this study will provide recommendations for the best wavelengths of light to use as a countermeasure to changes in biological rhythms and sleep patterns that occur during long-duration spaceflight. In addition, this research could improve spacesuit visors, spacecraft and habitat windows, and provide ideal lighting for astronauts and mission control workers during long-duration space exploration.

Software Tool Provides Enhanced Behavior Tracking and Feedback

Over the past four years, Horizon Performance and BHP research and mission operations personnel collaborated to design a software tool known as the Behavior Tracking Software System. The versatile software tool allows improved coding of human behavior in real time and can be modified for use in different settings where tracking behavior is critical. The tool provides assistance with the early detection and mitigation of BHP risks—particularly behavioral, interpersonal, and psychosocial issues—and helps automate the process of providing feedback to users and raters.

Evaluations and field tests were conducted throughout the BHP project to customize and refine the software tool, and these tests resulted in software that met both research and operational needs. This close collaboration between the research and operations groups and the developer, allowed a smooth transition of the Behavior Tracking Software System into the NASA operations environment.

As a clear demonstration of the benefit of research, operations, and external investigators working collaboratively, the tool was used in the recent astronaut selection process, including the rating of behavioral competencies and the generation of tailored summary reports. Specifically, the reporting feature facilitated rapid feedback to the astronaut selection team, and an hours-long paper and pencil process was replaced by a software-driven process occurring in mere seconds. Furthermore, the system complies with the highest level of data security requirements and uses the latest in data encryption methods.



Overview

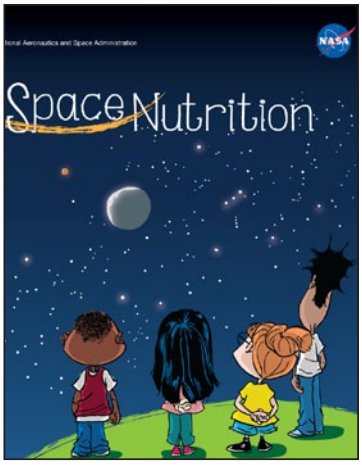
The Human Research Program supported a number of education and outreach initiatives in 2013 across multiple HRP Elements, the National Space Biomedical Research Institute (NSBRI) and NASA centers. Additionally, the HRP Elements help support other outreach initiatives including research internships, post-doctoral programs, and summer institutes for interns.

Space Nutrition iBook Available for Educators and Students

America's space program has come a long way from the early days when astronauts ate food packed in toothpaste tubes. Today, nutrition is known to be a key ingredient in astronaut health in space, just as it is for humans on Earth.

NASA scientists and educators have teamed up to publish a book, aimed at intermediate school students, that explains the role of nutrition in the space program. The free e-book describes how space nutrition research is conducted and highlights this important avenue of ongoing research at NASA. Educator guides, that suggest ways to incorporate the material into the classroom, along with mapping to National Science Education Standards, accompany the text.

"Spaceflight provides the backdrop to gain kids' interest," said a NASA nutritionist. "These books provide an opportunity to expand and educate beyond space to everything from science, math, nutrition, health, history, reading, and more. The fact that this material was developed by scientists actually conducting research on Earth and with astronauts in space provides insight into what it takes to conduct research at NASA, or anywhere—from an initial concept to the final publication in a scientific journal."



The free book is available in a PDF document and an interactive iBook.

The PDF is available at:
http://www.nasa.gov/centers/johnson/slsd/about/divisions/hacd/education/kids-zone.html

The interactive iBook version is available in iTunes:
http://itunes.apple.com/us/book/space-nutrition/id515790608?ls=1

NSBRI First Award Fellowship Program Receives Record Number of Applications

Since 2004, the NSBRI First Award Fellowship, formerly known as the Postdoctoral Fellowship Program, has continuously provided support for young scientists to conduct independent, space-related research projects in collaboration with an experienced faculty mentor in a U.S. laboratory. Since the program's inception, NSBRI has supported 34 postdoctoral fellows. During 2012-2013, First Award Fellows generated two book chapters, six peer-reviewed publications, 15 manuscripts, and 26 invited abstracts.

In March 2013, the request for application NSBRI-RFA-13-01, "Soliciting Postdoctoral Fellowship Applications," was released. Thirty-six proposals—more than in any other year—were submitted in response to the solicitation. A peer review of the applications occurred in August 2013 at the NASA Research and Education Support Services in Crystal City, Virginia. Five highly competitive applicants representing Washington University, Massachusetts Eye and Ear Infirmary, the University of Washington, Texas A&M University, and the University of Texas Southwestern Medical Center were awarded two-year fellowships. Fellowships will begin in early FY 2014.

NSBRI First Award Fellows and Mentored Research Fellows attend the Annual HRP Investigators' Workshop in February 2013. Fellows from both programs made presentations highlighting their research efforts at the event.

A student from Texas A&M University visits the JSC Space Vehicle Mockup Facility (SVMF) during the 2013 Summer Apprenticeship Program. The SVMF houses full-sized, high-fidelity crew trainers such as the ISS.

NSBRI Summer Apprenticeship Program Offers 9-Week Immersive Experience

The NSBRI Summer Apprenticeship Program is specifically intended for undergraduate, graduate, medical, and veterinary medical students, allowing them to participate in a nine-week immersive research experience focused on space-related biomedical research at Johnson Space Center, Ames Research Center, or Glenn Research Center.

For the 2013 Summer Apprenticeship Program, 181 applications were received representing 101 institutions of higher education in 34 states. Additionally, 75% of apprenticeships were awarded to women, and 12% were awarded to underserved and underrepresented students.

Throughout the program, apprentices are required to attend periodic research progress meetings at their respective centers and create written reports or posters emphasizing research accomplishments and other significant contributions. The optimal outcome of this program is for the research to culminate in a conference poster or presentation, or a manuscript in a peer-reviewed journal.

Since the conclusion of the Summer Apprenticeship Program in August 2013, nine manuscripts have

been in preparation and nine abstracts or poster presentations have been accepted at various national and international scientific conferences.

10th Annual Space Radiation Summer School Held at Brookhaven National Lab

The 10th annual NASA Space Radiation Summer School, held at Brookhaven National Laboratory (BNL), ran from May 29 through June 21, 2013. The course, offered by the Space Radiation Element, is intended to develop a pipeline of young radiobiology researchers interested in addressing the challenges posed by harmful radiation exposure to humans who will travel on space exploration missions.

A class of 18 U.S. and international graduate students and postdoctoral fellows completed the course. The curriculum included daily lectures on radiobiology, physics, radiation chemistry, and space radiation protection, taught by leading university and national laboratory biologists and physicists who are actively engaged in NASA space radiation research, and BNL experts in heavy ion experimentation and methods. In addition to the lectures, the students were able to gain hands-on experience by conducting cell experiments with the NSRL beam facility.

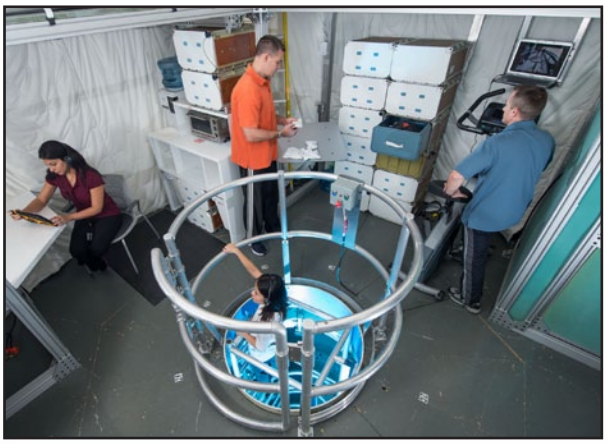
The 10th annual NASA Space Radiation Summer School participants stand outside the NSRL at Brookhaven in Long Island, New York.

Future International Life Science Research Announcement Solicitation

In FY2014, HRP expects to participate in an International Life Science Research Announcement (ILSRA) solicitation requesting flight experiment proposals. The ILSRA solicitation enables international cooperation, collaboration, and data and subject sharing for all International Partners (IP). The research announcement was developed in late 2013 with representatives from HRP and the Fundamental Space Biology Program as well as representatives from the IP space agencies including Italy, France, Germany, Europe, Russia, Japan, and Canada.

Human Exploration Research Analog (HERA) Mission Planned for FY2014

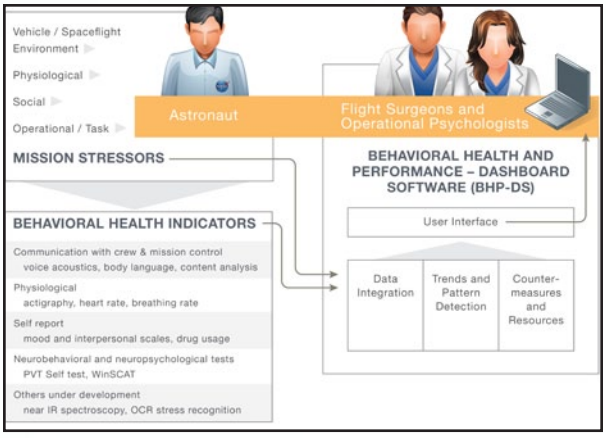
The first HERA isolation and confinement research mission is planned for FY2014. HERA is a ground-based, full-size habitat used as a spaceflight analog. Initial missions will consist of four independent 7-day tests, each with a crew of four. Research objectives for the mission will consist of several individual investigator studies that can be integrated on a non-interference basis. Operations will include pre-mission testing, in-mission operations, and post-mission activities consistent with ISS planning, thus simulating the spaceflight environment.
Upon the successful completion of the week long research missions, additional extended-duration missions of 14 days each are planned. The goal is to eventually conduct much longer 30-day missions which address HRP research goals to deliver products and strategies to protect the health and safety of spaceflight crews.



The first study utilizing HERA as an isolation analog will include a crew compliment of four living and performing task simulations within the facility for seven days.

BHP Dashboard Software to Help Support ISS In-Flight Psychological Evaluations

The Behavioral Health and Performance Dashboard (BHP-DS) provides a user interface to track astronaut behavioral health indicators in the context of events on the mission timeline, such as docking and EVAs, and environmental hazards such as noise



The BHP-DS will help medical personnel rapidly assess potential stressors and recognize emerging trends in behavior and recommend countermeasures to mitigate such trends.

levels and CO_2 exposure. These indicators are unobtrusively collected and integrated from multiple sources. When viewed by operational psychology personnel and flight surgeons, the dashboard provides meaningful behavioral health feedback and aids in the selection of countermeasures.

The technology company Pulsar Informatics was awarded a grant to work with BHP scientists to develop a requirements document based on a comprehensive review of current behavioral health monitoring methods in ISS operations. This guided the development of the BHP-DS software prototype designed to aggregate available behavioral health indicators and display them in the context of mission operational stressors and environmental stressors.

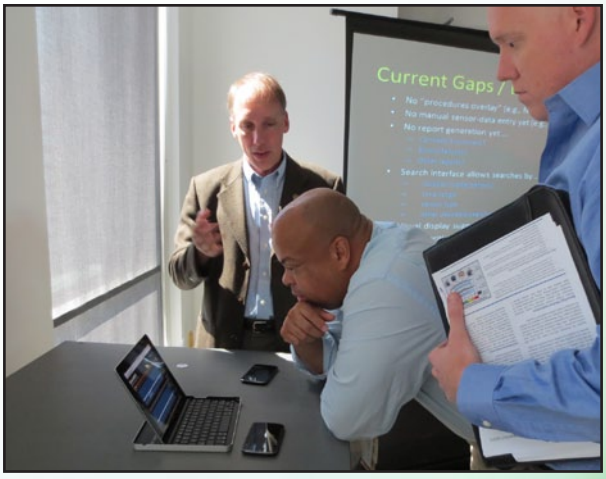
Pulsar worked closely with flight psychiatrists and psychologists to develop a specialized software module to assist with collecting astronaut behavioral health data during bi-weekly astronaut private psychological consultations.

Future work will focus on developing system features to aid flight surgeons in supporting astronauts during their weekly private medical conferences. The goal is to provide an informative tool to allow astronaut health issues to be detected and mitigated at an early stage.

Distributed System to Automate Spaceflight Biomedical Data Acquisition

Current in-flight medical operations require substantial amounts of time and effort from astronauts and ground controllers for managing medical data. There is no automated system for acquiring, synchronizing, storing, and communicating in-flight medical data to either crew medical officers or ground controllers and medical personnel. A general-purpose software platform, called SpaceMED, is in development and is designed to fill this critical gap. This system is intended to help integrate data from independently developed devices by supporting multiple communication standards, and is being developed in close partnership with HRP's Exploration Medical Capabilities Element.

When a medical instrument is turned on, that device is detected, communication is established, and data from that device are automatically collected, stored, and made available through any web browser connection. Both historical and real-time data will be accessible through the same SpaceMED interface. Eventually the system will support device control capabilities, for example to change sampling rates or gain factors, and will also support methods for easy association and dissociation of medical devices with a location or astronaut.



The SpaceMed platform will aggregate data from multiple devices via multiple protocols including Bluetooth.

Support for Bluetooth, 802.15.4 radio, and wired USB communications protocols have successfully been incorporated, and other protocols are being added as needed for the Exploration Medical System Demonstration (EMSD) project. The development of hardware sensors for demonstration purposes, as well as research into adapters for existing in-flight medical equipment, is ongoing.

Technologies Being Evaluated for Spaceflight Medical Oxygen Concentrators

Future exploration missions, which may last as long as 36 months, require advanced technologies for life support emergencies. This equipment would be used to treat medical emergency conditions such as smoke inhalation, angina, myocardial infarction, and decompression sickness, which would require patient ventilation with oxygen. An oxygen concentrator that uses cabin air provides a method of oxygen therapy while keeping the vehicle oxygen levels below the fire limit.

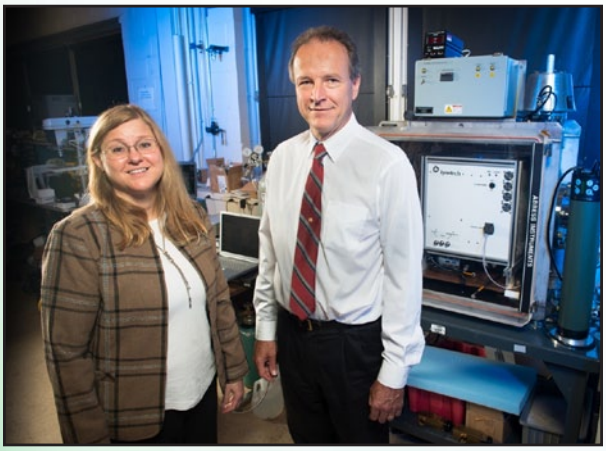
Researchers are currently pursuing two options for oxygen concentration: the pressure swing adsorption (PSA) method and electrochemical proton exchange membrane technology. The PSA method extracts oxygen from the air by using pressure-driven preferential adsorption to achieve molecular separation of nitrogen and oxygen. The electrochemical proton exchange membrane technology relies on liquid water and uses electrical energy to transport oxygen from the cathode to the anode as water.

Additional technology being pursued is the inclusion of a closed-loop oxygenation monitoring system that would monitor the patient's blood oxygen saturation level, and adjust the oxygen flow accordingly through medically certified protocols.

Final Samples for Nutrition Study Expected to Return on SpaceX Flight in FY2014

Nutritional assessments of astronauts before, during, and after spaceflight ensure adequate intake of calories, proteins, and vitamins during missions. To provide nutritional recommendations for long-duration space travel, HRP needs a better understanding of how nutritional status and general physiology are affected by the microgravity environment.

The Nutritional Status Assessment Supplemental Medical Objective (SMO) began in 2006 and is designed to evaluate ISS astronauts' nutritional status during spaceflight. Blood and urine samples are collected before and after flight and analyzed for more than 60 compounds, vitamins, and minerals. This nutritional data set can be utilized for various



Researchers stand in front of the prototype oxygen concentrator units. This research could lead to advanced technologies for the generation of oxygen safely in-situ.

An ISS crewmember enjoys a meal. The data from the Nutrition SMO study reveals important nutritional diagnostic information such as iron and calcium levels.

medical diagnostic or operational assessments. After a successful initial run, the Nutrition SMO has completed sample collections. The final samples are due to return on a SpaceX flight in early 2014, and will mark the end of this effort. Eight scientific papers reporting the results from the Nutrition SMO have been published to date, and more are in preparation or review.

Due to the valuable data obtained by the Nutrition SMO, similar proposals were requested in the 2012 NASA Research Announcement, and a follow-on study called "Biochemical Profile" was initiated. On-orbit data collections for this new project began in October 2013. The Biochemical Profile project provides for the collection, processing, database capability, and ethical distribution of biosamples and data to meet goals of scientific and programmatic relevance to the space program.

Ensuring the Stability and Efficacy of Medications for Long-Duration Missions

Medications are crucial for patient care on spaceflight missions, but every pharmaceutical drug has an expiration date—usually about two years after the date of manufacture. Currently, new supplies of fresh medications are regularly sent to the ISS. However, exploration missions are expected to last for two to three years, which is longer than most medications are thought to be effective and safe.

JSC pharmacists track the expiration dates for medications flown to the ISS. Expired medications are replaced with fresh supplies as needed to ensure drug efficacy.

It is known that some medications become less effective after their expiration date and some even have toxic breakdown products. HRP scientists, working with JSC pharmacists and doctors, have initiated several studies to ensure the safety and efficacy of the medication supply even for long-duration missions.

As medications on the ISS expire, they are often returned to JSC for laboratory analysis where they can be compared to a control group of medicines stored on the ground. Scientists are also considering a new analytical device, modified to function properly in microgravity, which would permit crewmembers to quickly analyze a medication dose for safety and efficacy just before use.

New options for packaging of medications are being investigated. HRP researchers are working collaboratively on advanced materials and packing techniques that would provide better protection from oxygen, humidity, light, and radiation.

Space Radiation Focuses on Degenerative Disease Risk During Exploration Missions

Current research in the Space Radiation (SR) Element is largely focused on quantifying risks that are caused by space radiation and establishing their mechanisms and effects. SR research is also focused on reducing uncertainties in the prediction of these same effects by risk-projection models.

Future research will have a greater focus on the risk of degenerative disease caused by space radiation exposure. These diseases include effects on the heart and the circulatory system as well as diseases related to aging. Investigations of mitigating strategies for

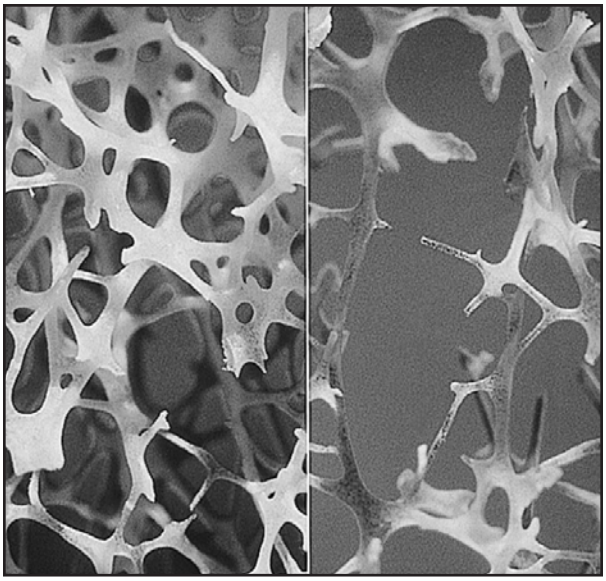
degenerative disease will be pursued if such diseases are found to be significant health risks for long-term missions beyond low Earth orbit. As part of this effort, SR will coordinate with NSBRI to quantify these risks and close the knowledge gaps related to degenerative disease that may be unacceptable for exploration missions.

New Technology Helps Determine Spaceflight Effects on the Lumbar Spine

The effects of long-duration spaceflight on the hip and spine can be described with clinical imaging technologies. Astronauts are scanned with two x-ray based technologies, commonly known as DXA or dual-energy X-ray absorptiometry and QCT or quantitative computed tomography. While these methods described spaceflight-induced changes in bone mineral density and structure, it is unknown if these changes result in an increased likelihood of bone fractures. If flight surgeons had the ability to estimate when fractures could happen, then they could apply mitigating strategies to protect astronauts during and after spaceflight.

Currently, astronauts fly 5 to 6-month missions on the ISS with a longer mission of 12 months planned for launch in 2015. These longer duration ISS missions enable researchers to expand their understanding of how bones change in the weightless environment. DXA scans are used to evaluate changes in bone mineral density in the spine, but there is no technique to measure the extremely small, detailed structure in the vertebrae in the lower back. If this bone micro-structure degrades, it can weaken the vertebra and cause it to collapse.

A new technique called Trabecular Bone Score (TBS) measures the grey color "texture" information extracted from DXA images of the lumbar spine. Studies have related TBS to bone micro-structure—where changes might be useful for estimating the possibility of vertebral fracture.



A normal bone structure (left) and one affected by osteoporosis (right). The Trabecular Bone Score (TBS) measures the grey color "texture" information extracted from DXA images.

A pilot analysis of 51 astronaut scans of the lumbar spine suggested that TBS can detect changes after an ISS mission. If applied to scans of retired ISS astronauts, TBS may yield additional insight as to how space-induced changes combine with the expected age-related changes to the lumbar spine. These data could be used in predictive models designed to estimate the probability of fracture or early onset osteoporosis after spaceflight.

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Human Research Program

2013 Fiscal Year Annual Report

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